Santa Clara University
DEPARTMENT of COMPUTER ENGINEERING
DEPARTMENT of ELECTRICAL ENGINEERING

Date: June 5, 2003

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Lemuel Diaz, Michelle Enyeart, Kristen Kristich, and Alan Moore

ENTITLED

Formation Robots

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF

BACHELOR OF SCIENCE IN COMPUTER ENGINEERING
BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

_____ THESIS ADVISOR

_____ THESIS ADVISOR

_____ DEPARTMENT CHAIR

_____ DEPARTMENT CHAIR

Formation Robots

by

Lemual Diaz
Michelle Enyeart
Kristen Kristich
Alan Moore

SENIOR DESIGN PROJECT REPORT

Submitted in partial fulfillment of the requirements
for the degree of
Bachelor of Science in Computer Engineering
Bachelor of Science in Electrical Engineering
School of Engineering
Santa Clara University

Santa Clara, California

June 5, 2003

Abstract

From science fiction to advanced research, robot technology has been fascinating the human intellect for years. Advances in technology over the past few years have allowed for many new developments in the growing field. One small but important area of research involves controlling multiple robots working together towards a single goal. Our project seeks to do just that, utilizing several sensing technologies together to create a system that controls a formation as it navigates from one destination to another.

A single robot can do a lot of things that human beings cannot, but the capability to control a group of robots as a single formation dramatically increases the possibilities. However, controlling a group of robots has its own difficulties. The goal of this project is to explore the potential of formation control with regards to the control strategy, the different possible sensors, and the ability to make it all user-friendly with a graphical interface. Additionally, the project aims to have a number of robots move in a formation from one location to another. The project successfully controlled a system of robots with linear, autonomous capabilities.

Acknowledgements

Formation Robots would like to give a special thanks to our advisors Professor Chris Kitts and Dr. Neil Quinn for their enthusiasm and outstanding support over the duration of our project.

Formation Robots would also like to thank Bob Dougherty for his commitment to the success of our project.

This project would not have been possible without the funding and support provided by various foundations and companies. We would like to thank The Santa Clara University Steering Committee, the National Science Foundation, and the Santa Clara University Alumni Board for allotting funds which allowed for the acquisition of the necessary hardware. A special thanks also goes out to Lockheed Martin for the usage of their Ultra Wide Band Units, and to ActivMedia Robotics for all of their technical support over the duration of the year.

This material is based upon work supported by the National Science Foundation under Grants No. 0079875 and No. 0082041. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Table of Contents

List of Figures vii

Chapter 1 Introduction 1

1.1 Motivation 1

1.2 Goals 2

Chapter 2 System Overview 4

2.1 The Robots 5

2.1.1 Software 8

2.1.2 Sonar 8

2.1.3 Maintenance and Problems 9

Chapter 3 Instrumentation 10

3.1 Ultra Wideband 10

3.1.1 Pulse Modulation 10

3.1.2 Interference Issues 11

3.1.3 Applications in our Project 11

3.1.3.1 Relative Distance 12

3.1.3.2 Angle of Arrival 12

3.1.3.3 Additional Applications 12

3.1.4 Advantages and Disadvantages 13

3.2 Digital Compass 13

3.3 Power Supplies 15

3.3.1 UWB 15

3.3.2 Hub 16

Chapter 4 Control 17

4.1 Programming Environment 17

4.2 Connecting to the User Interface 18

4.3 Behaviors 18

4.4 Implemented Behaviors 20

4.4.1 Lead Robot 20

4.4.1.1 The Go-To Behavior 20

4.4.1.2 The Avoid Obstacles Behavior 21

4.4.2 Following Robot 23
4.4.2.1 The Maintain Distance Behavior 23
4.4.2.2 The Maintain Angle Behavior 24
4.4.3 Behavior Extendibility 25
4.5 Overall Control Function 25
4.6 Getting into Formation 26
4.7 ARIA 26
Chapter 5 Graphical User Interface (GUI) 28
5.1 Software Tools and Components 28
5.2 Interface 29
5.3 Future Work 31
Chapter 6 Implementation and Test 32
6.1 Long Range Testing 32
6.2 Formation Testing 32
Chapter 7 Professional Issues 34
7.1 Social 34
7.2 Political 34
7.3 Economic 34
7.4 Health and Safety 34
7.5 Manufacturability 35
7.6 Sustainability 35
7.7 Environmental Impact 35
7.8 Usability 36
7.9 Lifelong Learning 36
7.10 Compassion 37
Chapter 8 Conclusion 38
8.1 Summary 38
8.2 Contributions 38
8.3 Future Extensions 38
8.4 Lessons Learned 39
Appendix A Digital Compass Code 40

Appendix B	Control Code	43
B.1	Database Access Code	43
B.2	Leading Robot Implementation	47
B.3	Go-To Behavior Implementation	53
B.4	Obstacle Avoidance Implementation	64
B.5	Following Robot Implementation	74
B.6	Maintain Distance Behavior Implementation	77
B.7	Maintain Angle Behavior Implementation	93
Appendix C	Assignment Algorithm Details	113
Appendix D	User Database Details	114
D.1	Creating the Necessary Structures	114
D.2	FormationRobots Tables	114
Appendix E	Graphical User Interface Code	116
E.1	Code for Formation Choice Page	116
E.2	Code for Chosen Formation Page	118
E.3	Code to Accept User Input	120
E.4	Code to Write to Database	122
Appendix F	Project Budget	124
Appendix G	User Manual	125
References		132

List of Figures

1-1	Terrain Mapping	1
1-2	Formation	2
2-1	System Components	4
2-2	Pioneer's turning velocity profile	5
2-3	Old Pioneer Microcontroller	6
2-4	Old Pioneer Motor-Driver Board	7
2-5	New Pioneer Microcontroller	7
2-6	New Pioneer Motor-Drive Board	8
2-7	Front Sonar Array	9
3-1	Pulse Modulation	10
3-2	Dual Antenna Configuration	12
3-3	CMPS01 Electronic Compass	14
3-4	Stamp & Compass Schematic	14
3-5	UWB Power Pack	15
3-6	Hub Power Pack	16
4-1	Overview of System Control	17
4-2	Illustration of Behavior Vectors	18
4-3	Behavioral Gain Factors	19
4-4	The Go-To Behavior	20
4-5	The Obstacle Avoidance Behavior	21
4-6	Adjustment of Obstacle Detection for Other Robots	22
4-7	The Maintain Distance Behavior	23
4-8	The Maintain Angle Behavior	24
5-1	Excerpt from Formations Table	29
5-2	GUI: Choose a Formation Page	29
5-3	GUI: Select Distance Page	30
5-4	GUI: Interactive Page	31
6-1	Test Layout	32
6-2	Long Range Results	32

6-3 No Wall Test Results 33
6-4 With Wall Test Results 33
6-5 Wall vs. No Wall 33

1. Introduction

In a world of ever increasing technology, the need for better and more efficient systems that can go into uncharted or inaccessible areas is becoming more prevalent. Single robot systems are very effective, yet the possibility for a formation of robots opens many more doors to exploration and convenience.

1.1 Motivation

As our team began considering the scope of the project, we also started considering the real world applications for such technology. We asked ourselves how our project could benefit technology and humanity and immediately thought of extraterrestrial applications. Our technology would allow us to survey and map the terrain of other planets such as Mars or Earth's moon. We would be able to perform altitude mapping of unknown terrain so that expensive human space missions would not have to. As displayed in Figure 1-1 depth information about a 13 Kilometer length of land is given through this altitude mapping. The mapped out areas would provide a lot of useful information such as places for good landing sites or valuable scientific data about craters.

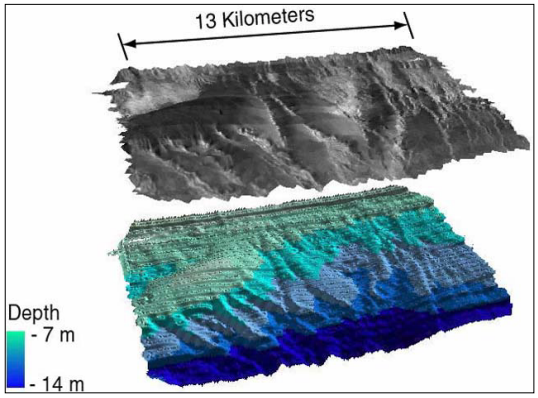


Figure 1-1 Terrain Mapping

Another practical use for this technology is factory automation. In factories there is often equipment or products that are bulky, heavy, or awkwardly shaped. These things cannot effectively be transported on a typical conveyor belt or with stationary robotic arms. A good solution to this problem is using the robots to move such objects. A formation of robots could be formed specifically to the parameters of the object and transported through the factory, all the while avoiding other workers and equipment. This could essentially save a company a lot of the time and man power that would otherwise be done manually.

1.2 Goals

When we started this project we had a few long term and short term goals in mind. Taking into account the possibility for future development by next year's team we set our goals high at first. Initially we wanted to create a system of robots that move in formation from one point to another. Another primary goal of our system is to have this formation be able to autonomously navigate around any obstacles that it may encounter on its way to the destination point. This is illustrated in Figure 1-2.

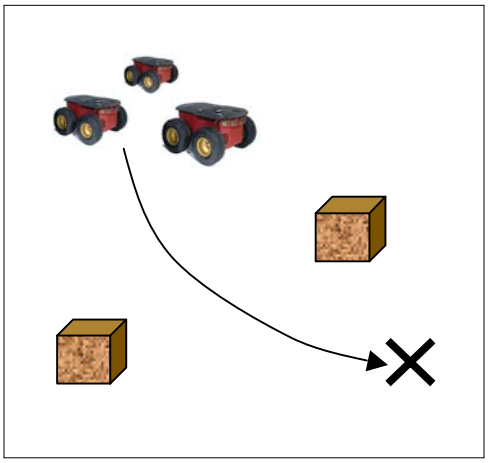


Figure 1-2 Formation

One of our early objectives was to determine a way to have an unlimited number of robots in our formation. Removing this constraint from our system would give us a wide range of new possibilities such as ad hoc networks, which would theoretically allow us to communicate over any physical distance.

Navigating around obstacles was a crucial portion of the overall goals of this project. We wanted to take into account all possible obstacles and their positions.

Autonomy, although not critical to the functionality of our system, was one of our main goals. We wanted the user to be able to plug in a destination into the user interface and the formation gets there without any further necessary intervention.

As our project progressed our goals were redefined to fit a more suitable timetable. We quickly realized that taking into account every single possible obstacle and formation related problem would take an inordinate amount of effort and time. Thus we narrowed our system to two robots with predetermined markers of success. These new markers included: getting everything to communicate and work correctly, effectively being able to stay in a predetermined formation, detect obstacles, create a graphical user interface, and still have this system be largely autonomous.

With all of these redefinitions taken into account we were able to finalize our goals. The goals are:

1) Maintain a Formation

2) Get to a destination

3) Avoid Obstacles

4) Autonomous System

2. System Overview

The Formation Robot system consists of the following seven main subsystems: a robot, Ultra Wideband device, Compass, Graphical User Interface, wireless communication subsystem, a software control subsystem, and a Laptop. Each subsystem was independently designed and then integrated once all of the hardware, software, and electrical components necessary for each were complete. The robot is a purchased unit that consists of its own micro-controller to communicate with the sonar and the motor drivers to control the drive path of the robots.

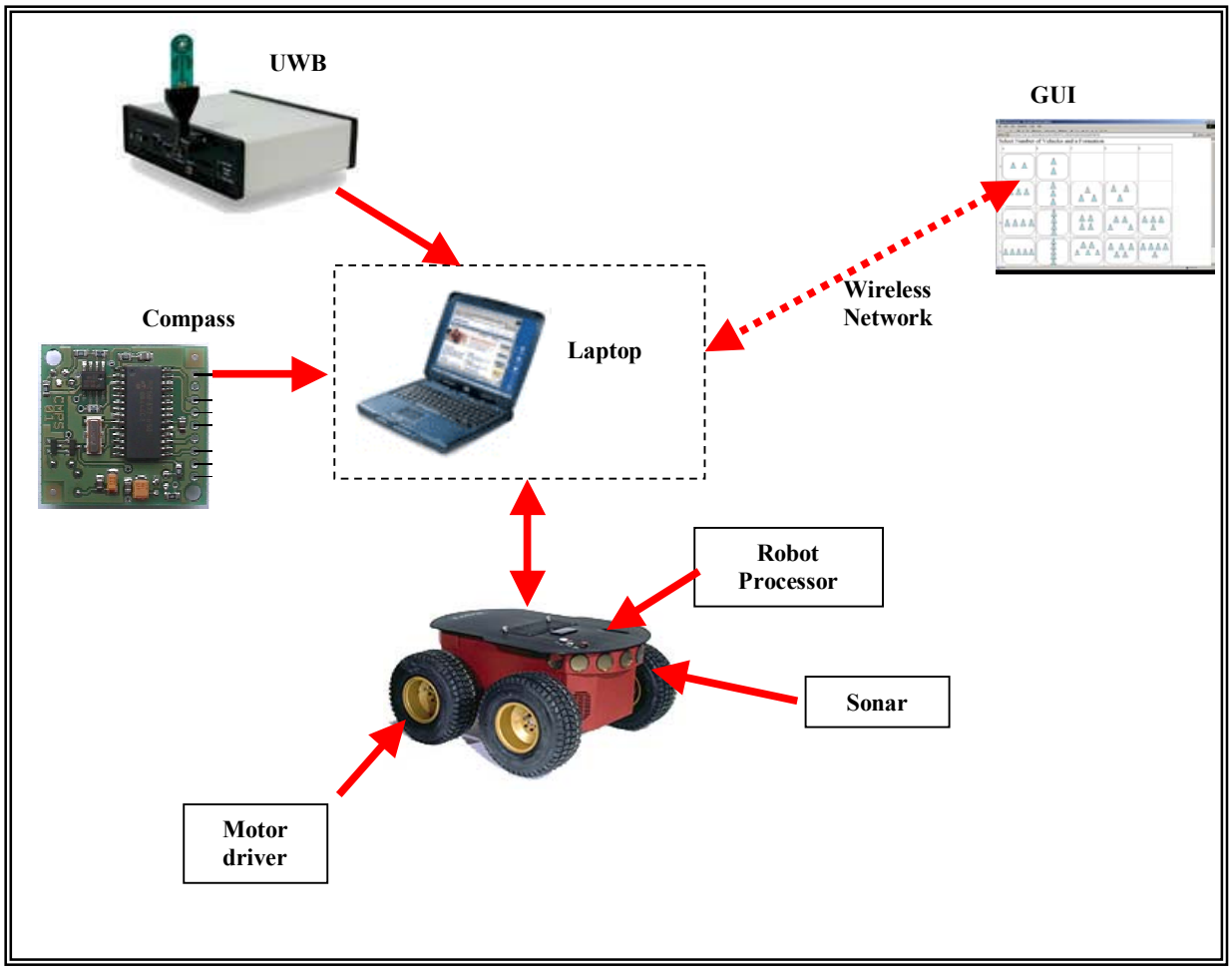


Figure 2-1 System Components

The Ultra Wideband system, the key feature of our project, is used to control the distance between each of the robots in the formation. Next, the Compass system uses an electrical compass to control absolute direction for each robot. Then each robot of the system takes the angle from each compass and uses the angles to correct each robots' orientation. The Graphical User Interface is designed to simplify the control of the system as a whole. A wireless network is used to transfer commands from the Graphical User Interface to each of the robots. The laptop and software control work as a server, to combine data from each of the subsystems. This is done in order to control the formation of robots, moving from the initial point and around obstacles to the final destination.

2.1 The Robots

The most important mechanical units used in our project were the robots. When the project was first proposed, we had the option of using one of two robot models made by ActivMedia Robotics. The first choice was the AmigoBot, a smaller, but more mobile robot. The second was the Pioneer AT, an all-terrain vehicle which had the capability to carry a large load. After weighing the capabilities of each robot we chose the Pioneer AT. By using the Pioneer, we will have more leeway for future design expansion. The Pioneers drive capabilities were also important. It had the ability to rotate 360 degrees in one place, making it easy to move around tight obstacles (Figure 2-2). Also, the Pioneer is managed by an onboard microcontroller and mobile-robot server software. It is a four-wheel drive mobile robot that is truly intelligent, containing all of the basic components for sensing and navigation in a real-world environment, including: battery power, drive

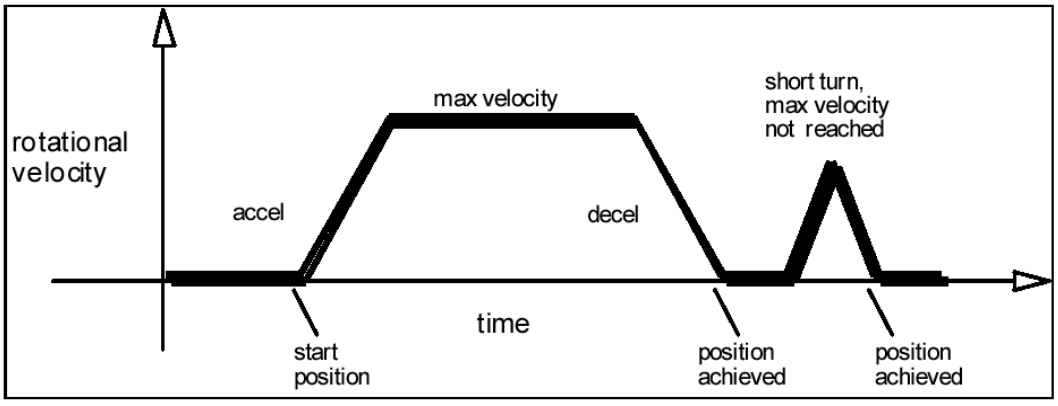


Figure 2-2 Pioneer's turning velocity profile

motors and wheels, position-speed encoders, integrated sensors, and accessories.[1]

The ActivMedia robot is the server in a client-server environment. It handles the low-level details of mobile robotics, including: maintaining the platform's drive speed, heading over uneven terrain, and acquiring sensor readings from the sonar. The robots require a client connection: software running on a computer workstation (laptop) connected with the robot's controller via a serial link that provides the high-level, intelligent robot controls, including obstacle avoidance and path planning. The robot performs these tasks through its onboard computing system, which consists of a microcontroller (Figure 2-3; Figure 2-5), the heart of the robot, and the motor-driver board (Figure 2-4; Figure 2-6), which controls all four motors to make sure they rotate appropriately.

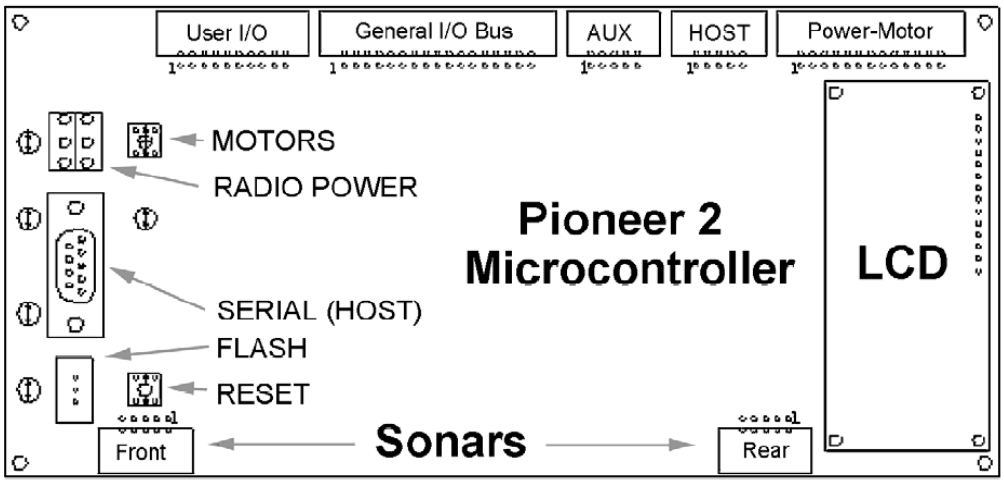


Figure 2-3 Old Pioneer Microcontroller

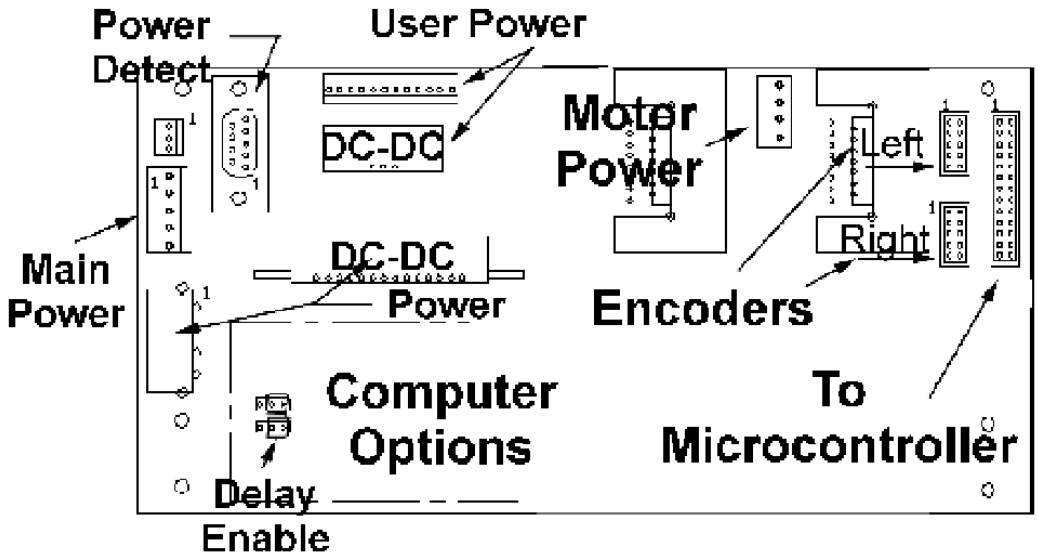


Figure 2-4 Old Pioneer Motor-Driver Board

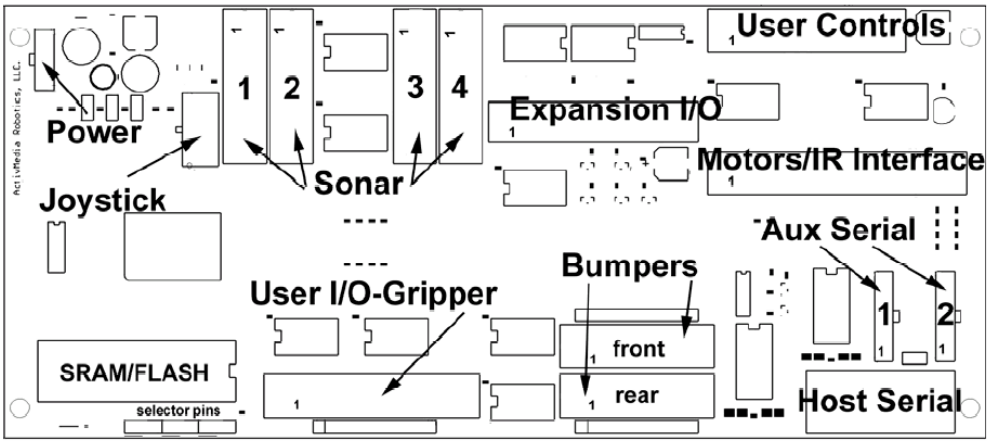


Figure 2-5 New Pioneer Microcontroller

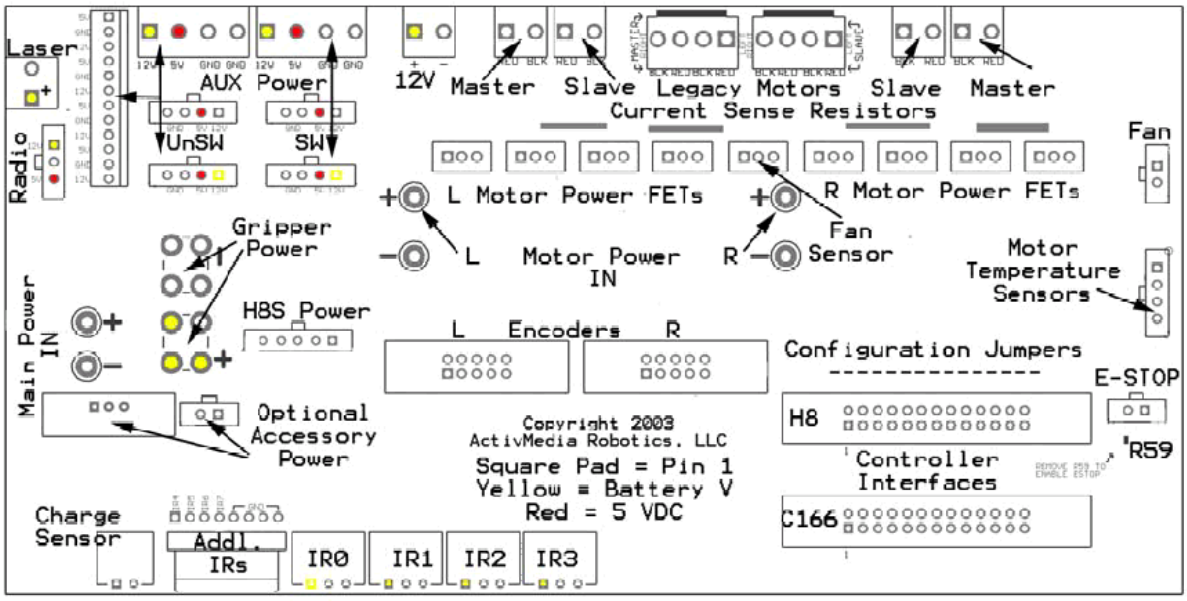


Figure 2-6 New Pioneer Motor-Drive Board

2.1.1 Software

The ActivMedia robots came with two basic software programs; ARIA and Saphira. ARIA uses a C++ based development environment that provides a robust client-side interface to the robot's controller and accessory systems. In fact, we manipulated the ARIA software so that our robot system would interact with the other devices that we attached (See Section 4.7 for more ARIA information). Saphira is a higher-level environment that combines itself with ARIA to include a GUI simulator for robot movement.

2.1.2 Sonar

The robot can support both front and rear sonar arrays, each with eight transducers that provide object detection and range information for feature recognition, as well as navigation around obstacles. We only chose to enable the robot's front sonar array, since using the rear sonar would cause interference with other robots in the formation. The sonar positions in all arrays are fixed: one on each side of the robot, and six situated in the front spaced at 20-degree intervals. Together, they provide 180 degrees of seamless sensing for the platform. Sensitivity ranges from ten centimeters to nearly five meters (Figure 2-7).

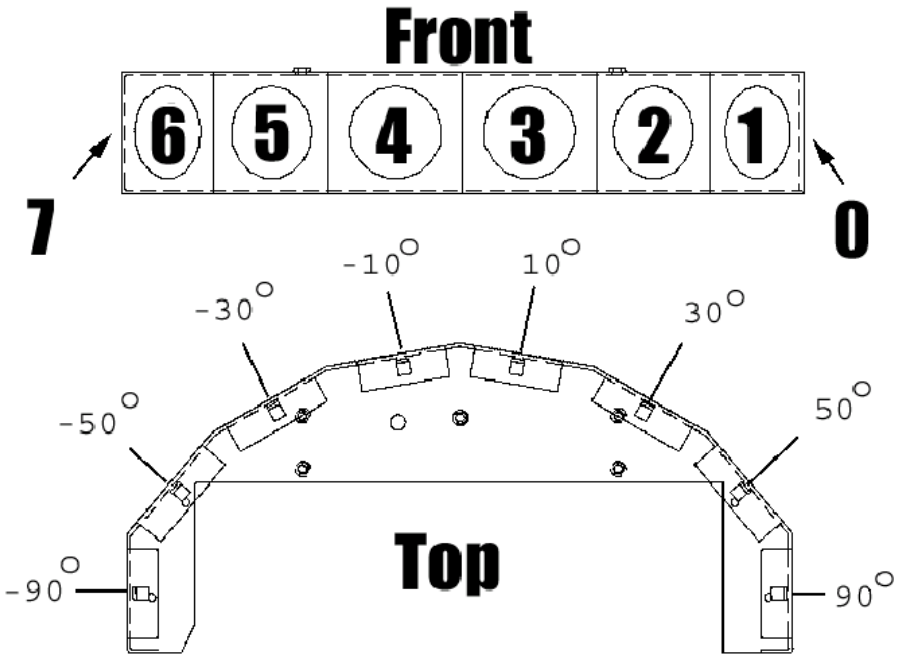


Figure 2-7 Front Sonar Array

2.1.3 Maintenance & Problems

To our surprise, the robots purchased from ActivMedia Robotics needed constant maintenance and came with some major problems that affected the design and testing process of our project. The first problem encountered occurred while performing necessary maintenance on the first robot purchased. This robot had to have the software system updated and the drive belts retightened. Unfortunately, we were unable to upload the new system software onto the microcontroller, requiring us to send in the microcontroller for a replacement. After replacing the microcontroller, this robot had no further problems. Another problem that arose came from the configuration parameters (Appendix: A) that had to be readjusted after each software update. Adjusting these parameters was based on a trial and error process, which made it very time consuming.

The final robot malfunction occurred in two robots when their Motor Driver circuit boards blew. This last malfunction caused havoc in the group since we were unable to test our system while the robots where being serviced. Once all the robots were fixed, we were able to perform tests as needed.

3. Instrumentation

3.1 Ultra Wideband

Ultra wide band (UWB) is a wireless communication device that uses a wide spectrum of frequencies as apposed to a narrow band frequency. For example, a similar wireless device called Bluetooth transmits only at a frequency of 2.4 GHz ± 1MHz. UWB has the capability to transmit at extremely high rates. The current stage of the technology allows a maximum transmit speed of about 500Mbps of raw data. Most other wireless communication devices don't even come close to the rate of transmission that UWB does.

3.1.1 Pulse Modulation

To understand why UWB is significantly better in both previously stated parameters, an examination of the modulation scheme must first be presented. Most people are familiar with the common modulations schemes referred to as AM and FM. These are the schemes allocated by the FCC specifically for radio transmissions. AM uses amplitude modulation and FM uses frequency modulation. Both schemes are very effective, but come with a specific frequency parameter. Both AM and FM require signals to be transmitted at very specific frequencies, called narrow band frequencies.

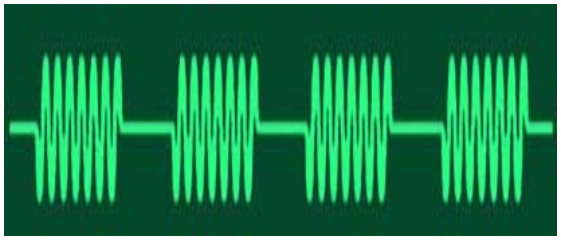


Figure 3-1 Pulse Modulation

UWB uses a slightly different modulation scheme, called Pulse Modulation (PM). Pulse modulation uses short, low powered bursts of energy, on the order of picoseconds and milliwatts, to transmit its signal (See Figure 3-1). These short bursts of energy are transmitted through the antenna of the UWB unit and are received by another unit. The received bursts are then decoded by taking into account the distance between bursts. For example, if a burst is received a picosecond early then it is decoded as a binary 1; if it is received a picosecond later than expected then it is decoded as a binary 0. This is a simplified version of the complicated coding and decoding methods of a real UWB transmission.

3.1.2 Interference Issues

UWB is not a narrow band frequency device. That is, it does not transmit only at specific frequencies. UWB still has a center frequency, but the band is normally spread between two and four GHz. The units that were used in this project had a center frequency of 4.7 and were spread over 3.2 GHz. This ultra wide range of transmit frequencies gives some interesting characteristics to the system. The devices are no longer susceptible to narrow band interference. This can best be illustrated by comparison. When listening to the radio you may experience cross over from another station that is close to the channel you are listening to. This happens because the transmit frequencies are so close that they may in fact overlap sometimes. That interference is the narrow band frequency interference. UWB does not have that problem because information is sent over a range of frequencies instead of a single frequency. Even if there is a high power spike at a single frequency within the transmit range of the UWB it will only disturb an extremely small part of the overall signal

This works both ways. The signal is not only unsusceptible to narrow band interference, but it does not interfere with narrow band frequencies either. These bursts of energy that make up the transmission signal are very low powered. Due to the fact that these bursts are spread over 3.2 GHz the signal comes out looking like Gaussian noise (sometimes referred to as white noise). This type of noise is considered to be part of the noise floor, or the noise commonly associated with a common, public environment.

3.1.3 Applications In The Project

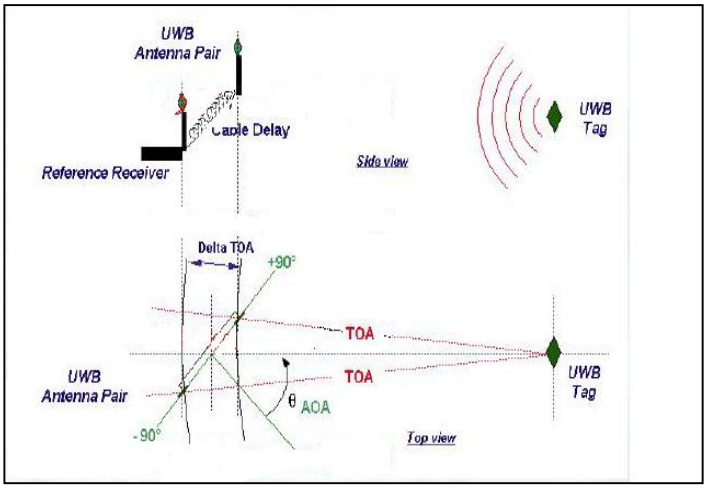
Having a better understanding of what UWB is will give you a better idea of the reasons it was used in this project. UWB had capabilities such as distance between units, relative angle information between units, fast transmit speeds, and having no requirement for line of sight. All of these capabilities were considered useful given the scope and motivations of our project.

3.1.3.1 Relative Distance

The UWB units gave us the ability to determine the distance between units. This was an essential part to maintaining the formation of the robots. The distance information is obtained through the calculation of the time of flight between the antennas of each unit. The time of flight, also referred to as time of arrival (TOA), is the time that it takes for a signal to get to the receiving antenna and back. That time of flight is then converted into a distance by mathematical equations.

3.1.3.2 Angle Of Arrival

When the UWB units are configured in the dual antenna mode as pictured in Figure 3-2 they can give valuable angle information. As pictured, a relative angle between units is found. Here the time of flight, shown on figure as TOA (time of arrival), is then converted into a distance by taking into account the travel speed of the energy burst and the distance between the dual antennas.



3-2 Dual Antenna Configuration

3.1.3.3 Additional Applications

Something very interesting can be done with the UWB units in a 3-D environment. Using a third antenna we can also have the capability for a Cartesian "Z", or altitude, calculation. Having three antennas on each robot gives us the potential for applications such as altitude mapping. The three antennas cover the x, y, and z planes of 3-D space. This means that a three-antenna configuration could give distance away, relative angle difference, and relative altitude difference.

3.1.4 Advantages And Disadvantages

Some of the key advantages that UWB has over other wireless communication devices include: no line of sight required, interference characteristics, relatively low power, and high transmit rates. One of the main areas where this technology is inferior to other communication devices is the distance a signal can travel. Project tests indicate that the UWB units start to fail after about 100 feet apart. This can be slightly increased if the acquisition header time is increased. Increasing the acquisition header essentially makes the UWB units wait for a longer period of time before decoding the received data. It does this to ensure that all the data that was sent has been received.

3.2 Digital Compass

Direction control was crucial to the mobility of the robots' formation. Without one, it would be near impossible for the robots to stay in the correct formation. We were able devise two methods to control the robots' direction; angle of arrival and an electronic compass. The angle of arrival method would use a 2-antanna configuration to compute the absolute direction and location of each robot. Ultimately, angle of arrival would give the best data, but due to lack of technical support from the manufacturers, this method was not implemented. Therefore, we chose an electronic compass, which would calculate the absolute angle of the robot by using a 360-degree measurement. This method was the quickest to implement, unfortunately the only drawback was that it did not have the robust capabilities of angle of arrival.

We used the CMPS01 electronic compass (Figure 3-3) as the solution to direction control. This compass module has been specifically designed for use in robots as an aid to navigation. The compass uses the Philips KMZ10A magnetic field sensor, which is sensitive enough to detect the earth's magnetic field. The module generates a number that indicates the bearing of the robot in relation to the local magnetic field. The aim was to produce a unique number to represent the direction the robot is facing. This number can then be read by an OOPic microcontroller or a Stamp.

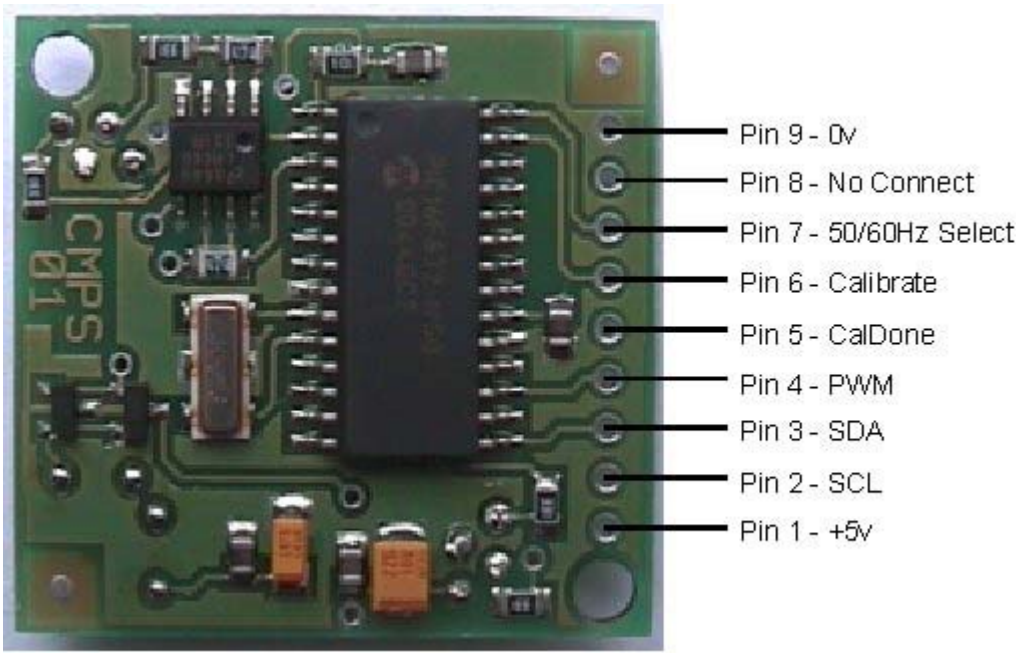


Figure 3-3 CMPS01 Electronic Compass

The compass module requires a 5 Volt power supply at a nominal 15 mAmp. It receives its bearing data from PWM. The PWM signal is a pulse width modulated signal with the positive width of the pulse representing the angle[2].

The compass module requires a small processor to read the magnetic field data. We used the BS2sx Stamp from Parallax to calculate data from the compass and pass it through the serial port. The Stamp uses the BASIC programming language, where it can

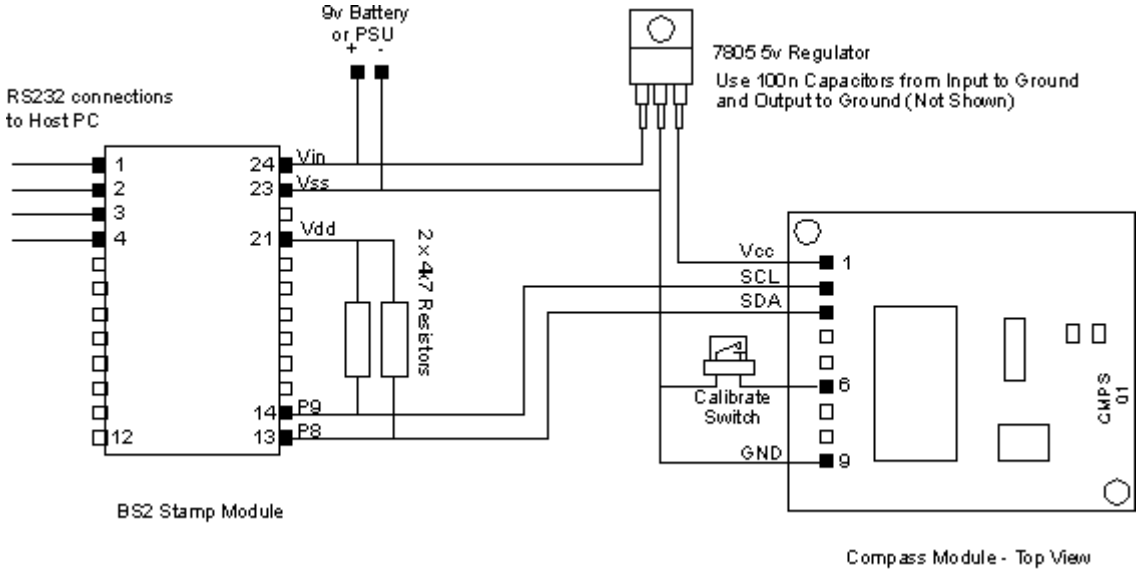


Figure 3-4 Stamp & Compass Schematic

perform 10,000 instructions per second (50 Mhz clock), and can store 82K programs (16K total), but only able to run one program at a time.

Implementing the Compass module with the Stamp was very easy considering everything was documented on the Internet[3].

3.3 Power Supplies

One criterion behind our project was to design the robots to be completely autonomous. This means that all devices connected to the robots had to have their own power supply to avoid the use of a cord. Overall, we had to design two types of battery packs, one for the Ultra Wideband units, and another to power a hub, which was used to connect the UWB to the laptops.

3.3.1 UWB

In the beginning stages of the project, the UWB power packs were crucial because they gave us the ability to test the capabilities of the UWB. When designing the power packs, we focused on simplicity and on battery life. It would need to put out a 7 Volt and 3 Amp for at least an hour, so we chose regular 7.2 Volt and 3 Amp/hrs RC car batteries. These would make it easier to recharge the batteries. In the long run, we were able power the UWB units for about 1.5 hours (Figure 3-5).

Parts Included:

- 7.2 Volt RC Battery
- 5 Amp Fuse
- Power Switch

Figure 3-5 UWB Power Pack

3.3.2 Hub

The hub power pack required a little more thought to design than the UWB power packs. The same RC care batteries were used, in addition to plus we added a voltage regulator at 5 Volts / 2 Amp to make sure we did not over power the hub (Figure 3-6).

Parts Included:

- 7.2 Volt RC Battery
- 5 Volt Voltage Regulator

Figure 3-6 Hub Power Pack

4. Control

The Control is the set of code that takes the desired action from the user and gives the robot instructions which implement that action. It is essentially the translator between the user and the robot hardware. The code consists of the program to access the user database, the programs to determine the action to be taken by each robot, and the interface that controls the robot and it various motors. This last interface is known as ARIA and was provided by ActivMedia with the purchase of the robots. Figure 4-1 further illustrates the relationship between the Control and the rest of the Formation system.

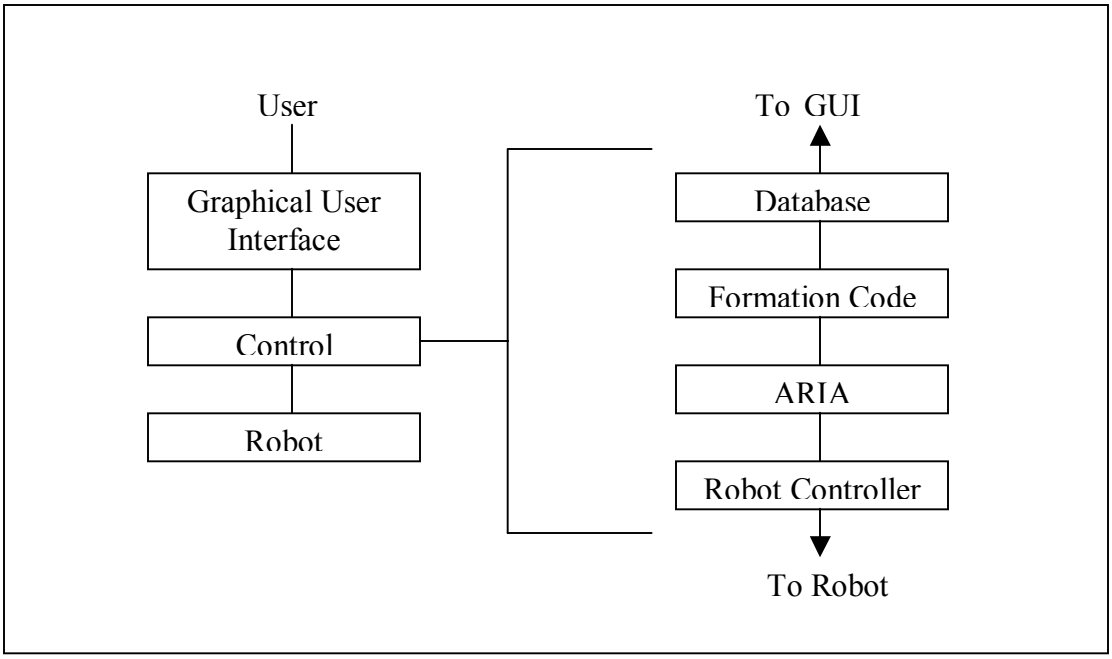


Figure 4-1 Overview of System Control

4.1 Programming Environment

The control code was written in C++ using the Microsoft Visual C++ Professional Studio. It primarily consists of executable programs that use the Windows console and have been successfully tested on Microsoft Windows 98 and Windows 2000.

4.2 Connecting to the User Interface

The control accesses the user input through the user database. The database is a mySQL database consisting of a formation table and a destination table. For more information on the database, refer section 5.1 in the Graphical User Interface portion of this paper.

The control accesses the database with the help of mysql++, an open-source API for MySQL and C++. It has different version that work with gnu or Microsoft Visual C++. It comes with a user manual and a brief tutorial[4]. The code included in this project is primarily based off the example entitled "custom3" in the tutorial. In general, it uses typical SQL commands, but in a more complicated way.

Refer to Appendix B.1 for the actual database access code.

4.3 Behaviors

To implement the various algorithms of the system, we implemented a behavioral approach. This approach treats all the different aspects of the system that are acting on the formation, such as maintaining the formation and obstacle avoidance, as vector forces. These aspects are things in the environment that would cause a change in the formation's position or velocity. For example, the destination of the robots acts as a vector that pulls the formation towards it while obstacles in the formation's path act as vectors pushing the robots away. Figure 4-2 helps to illustrate the different vector forces

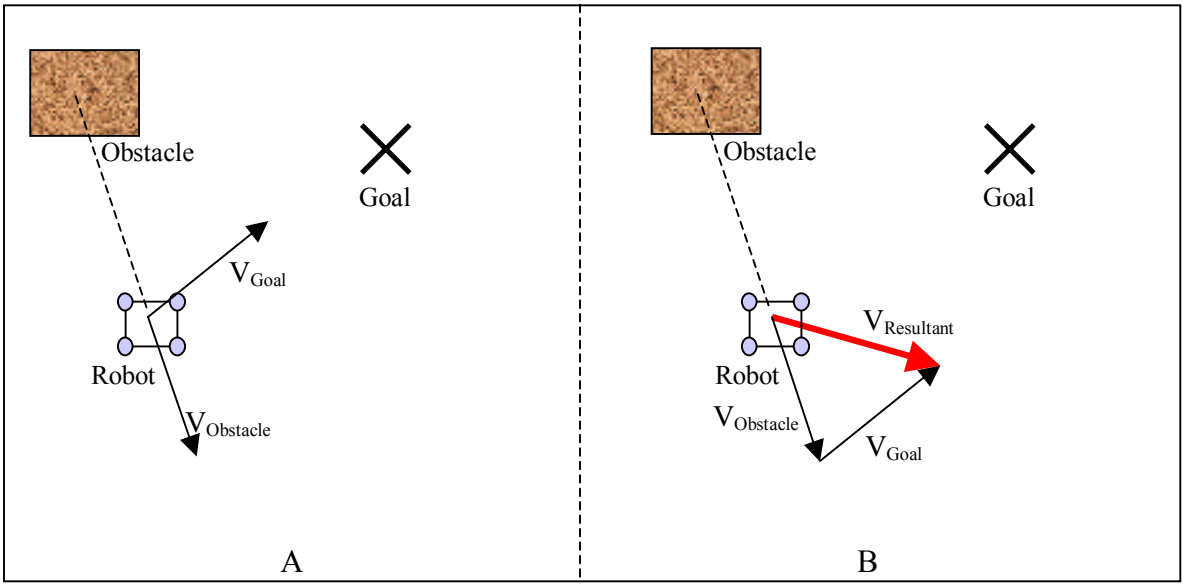


Figure 4-2 Illustration of Behavior Vectors

acting on the system.

Side A of figure 4-2 shows the two vectors that are acting on the robot. V_{Goal} is the force pulling the robot towards its goal or destination. $V_{Obstacle}$ is the force vector pushing the robot away from the obstacle. Side B of the diagram illustrates the vector sum of the two forces that creates $V_{Resultant}$. This vector is the force that now steers the robot. As the robot moves away from the obstacle, the $V_{Obstacle}$ will decrease so that V_{Goal} will become the predominant steering force in the system.

By using the vector approach, the system does not have to take into consideration every possible obstacle or goal configuration. Instead, we create individual instructions for each type of vector or behavior, and then by putting them all together, the system achieves its goal in many different situations.

The behavioral approach also allows us to control the significance, or weight, of one behavior over another. For example, if it was important that the robots maintain a rigid formation, then we could set the weight factor for the formation behavior higher than the weight of any other behavior. For example, in Figure 4-3, the standard resultant vector is shown in side A, while in side B, the weight of the obstacle behavior has been increased by a factor of two. This effectively changes the resultant vector so that the robot moves much more dramatically than the standard resultant.

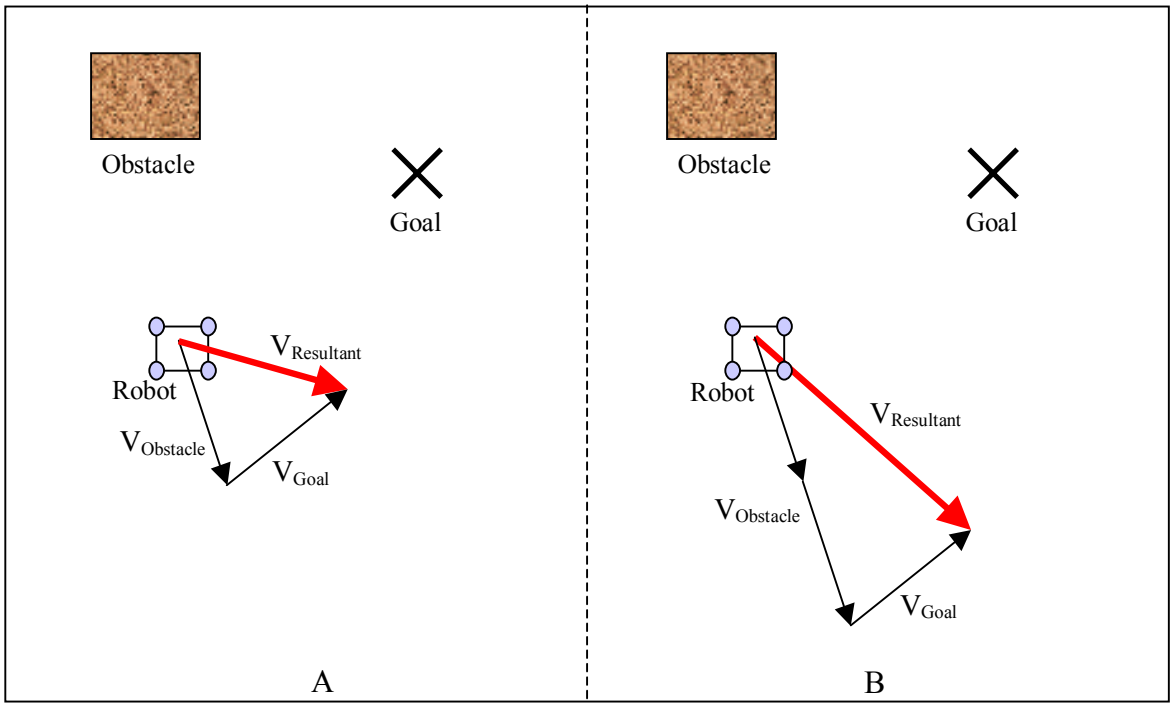


Figure 4-3 Behavioral Gain Factors

4.4 Implemented Behaviors

The control system divides the behaviors into two types. The first type determines the action of the leading robot and the second type controls the following robot(s). The lead robot could be simply any robot in the system chosen at random. In our current implementation, the lead robot is whichever robot is running the leader application.

4.4.1 Lead Robot

4.4.1.1 The Go-To Behavior

The lead robot has two behaviors. The first is the Go-To behavior. This behavior calculates the direct distance between the current location and the goal location, and the action required to get the robot moving in that direction. This is illustrated in Figure 4-4 below. The diagram shows a formation of robots and their goal.

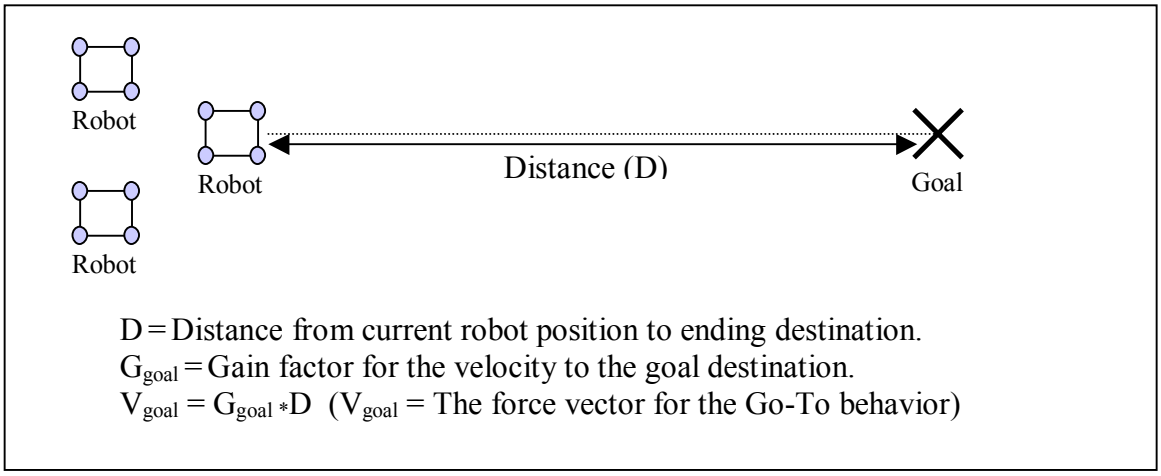

Robot
Robot
Robot
Distance (D)
Goal
D = Distance from current robot position to ending destination.
G_{goal} = Gain factor for the velocity to the goal destination.
$V_{goal} = G_{goal} * D$ (V_{goal} = The force vector for the Go-To behavior)

Figure 4-4 The Go-To Behavior

This function gets the destination coordinates from the user database and directs the robot to that location. The speed and direction vary depending on the current position of the robot. The current implementation uses the following equation to calculate the desired speed:

$$\text{Velocity} = \sqrt{(D * 200 * 2)} \quad \text{mm/s} \qquad (1)$$

Where D is the distance from the current position to the goal. This equation is part of the ARIA package. The velocity is calculated in millimeters per second.

The standard Go-To function was already implemented as part of the ARIA system, however, some changes were required to adjust the function so that it complied with the vector approach to a behavioral application.

The behavior is considered complete when the robot has reached its destination, or is within 100 millimeters of the destination. This 'close enough' value can be changed depending on how accurate the formation needs to be. However, for this project, the 100 millimeters value is good enough. Additionally, if the value is too small or zero, then the robot may have trouble actually stopping at the exact desired location.

For more information on the implementation of the Go-To behavior, please to Appendix B.3.

4.4.1.2 The Avoid Obstacles Behavior

The second behavior implemented on the lead robot is the behavior to avoid obstacles. This behavior calculates the force vectors that push the robot away from obstacles and the action required for the robot to avoid the obstacle. This behavior is illustrated in Figure 4-5. Side A of the diagram illustrates the various forces acting on the robot while side B illustrates the calculation of $V_{Obstacle}$ by creating the vector sum of all obstacle vectors.

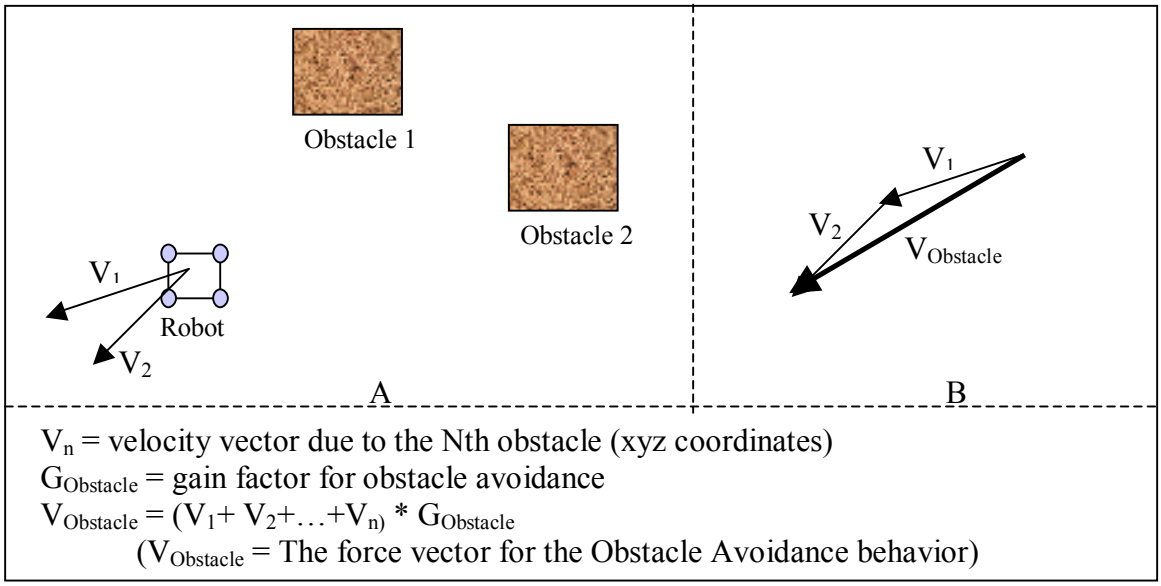


Figure 4-5 The Obstacle Avoidance Behavior

This function gets the location of the nearest obstacle using the sonar range installed on the robots. The speed and direction that the behavior directs the robot to move vary depending on the size and proximity of the obstacles. The current uses the following equation to calculate the new direction and desired speed of the robot:

$$\text{Velocity} = \text{current speed} - \text{range of nearest obstacle} \quad (2)$$

$$\text{Angle} = .5 * (\text{current angle} - \text{angle of obstacle}) \quad (3)$$

Again the velocity is counted in millimeters per second and the angle is calculated in degrees counterclockwise from the x-axis.

An extra adjustment to the implementation of this behavior checks to make sure that the obstacle the sonar senses is not actually another robot in the formation. It checks this by using the information about the formation, such as the coordinates of all the robots in the system. Then, it calculates the degrees in the visual radius of the sonar that the other robots are occupying. The behavior can then ignore any obstacles within the specified range and angle of the other robots. This is more clearly explained in Figure 4-6. In this diagram, there is a formation of two robots. The robot in the rear is using the obstacle avoidance function and must detect the forward robot without misinterpreting the latter as another obstacle. The lightly shaded area indicates the range of the sonar, and the darker shading represents the range that the control system must ignore as another robot.

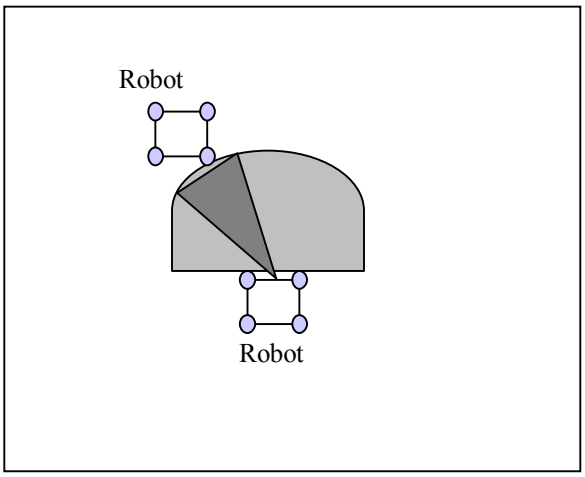


Figure 4-6 Adjustment of Obstacle Detection for Other Robots

The behavior does not have a point at which it is considered complete because obstacle avoidance is a continuous process while the robot is in motion. For more information on the implementation of the Obstacle Avoidance behavior, refer to Appendix B.4.

4.4.2 Following Robot

4.4.2.1 The Maintain Distance Behavior

The following robots also have two primary behaviors. The first behavior maintains the distance between the leader and the follower. This behavior calculates the force vector acting on the following robot that pushes or pulls the robots into the proper position in the formation. Figure 4-7 illustrates the behavior more clearly.

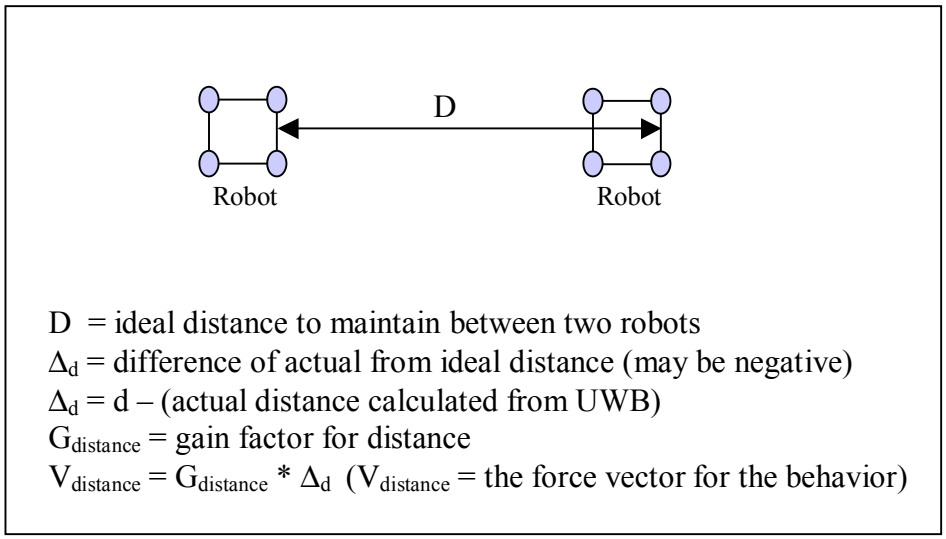

D
Robot
Robot
D = ideal distance to maintain between two robots
Δd = difference of actual from ideal distance (may be negative)
Δd = d – (actual distance calculated from UWB)
Gdistance = gain factor for distance
Vdistance = Gdistance * Δd (Vdistance = the force vector for the behavior)

Figure 4-7 The Maintain Distance Behavior

The actual values for the speed and direction of the robot are determined by the difference of the actual from the ideal distance of the formation. More precisely, the following equations determine the velocity of the robot in the system:

$$\text{Velocity} = \text{Distance Error} \tag{4}$$

In this case, the Distance Error is the current distance between robots minus the desired distance between the robots. This creates a simple linear acceleration with a maximum velocity currently set at 500 millimeters per second. This maximum can be changed, but it is currently kept at 500 for safety purposes.

The implementation of this function relies on the Ultra Wideband functionality that calculates the range between the two units.

This behavior does not have a point at which it is considered complete because maintaining the proper formation is a continuous process. This behavior begins once the user has specified a formation and stops when the user stops the application. For more

information on the implementation of the behavior to maintain distance, refer to Appendix B.6.

4.4.2.2 The Maintain Angle Behavior

The second behavior of the following robots is the behavior that maintains the angles within the formation. The function is responsible for keeping the robot at a specific angle relative to the leader. Essentially, this function ensures that the formation is properly arranged beyond simply maintaining distances. This behavior relies on the Ultra Wideband units to calculate the angle of arrival information. Figure 4-8 further explains this behavior. The diagram shows one possible configuration of the robots in the formation on side A. Side B illustrates the appropriate orientation for both robots in the system. In this case, the robot needs to turn $\Delta\theta$ to maintain the desired (ideal) angle at the rotational velocity indicated by V_θ.

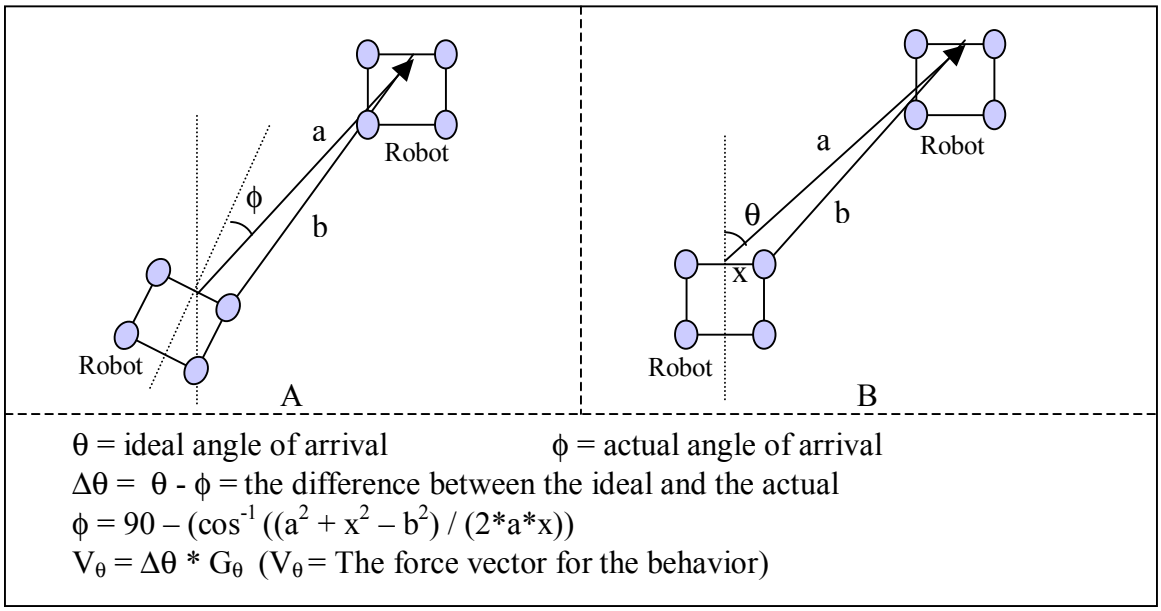


Figure 4-8 The Maintain Angle Behavior

This behavior relies on the angle of arrival information calculated with the dual antenna configuration of the Ultra Wideband units. However, we were unable to utilize the angle of arrival functionality due to versioning constraints. The manufacturer no longer supports the version of the Ultra Wideband units used in the current system,

therefore it was not possible to utilize the dual antennas. Instead of using the angle of arrival method, we used a compass to determine absolute angle. This value gives us the direction that the robots are facing at any given moment. This primarily corrects the case when the robots begin to veer off of the straight path and allows us to ensure that the robots are all facing the same direction. The function calculates the angle to turn with the following equation:

$$\text{Angle} = \text{desired angle} - \text{current angle} \quad (5)$$

For more information on the compass and maintain angle behavior implementation, refer to Appendix B.7.

4.4.3 Behavior Extendibility

One goal of our system was to ensure system extendibility, or the behavior to use any number of robots in a formation. One way this goal was achieved involves the behaviors. It may appear difficult to add more robots to the system without extensive adjustments to the function; however, no change is required. Adding more robots to the system should not affect the behaviors because, by maintaining a set distance from the leader and maintaining a relative angle (as illustrated in the sections 4.4.2.1 and 4.4.2.2) from the leader, the robots should automatically maintain a set distance from all other following robots. Essentially, by ensuring that each robot is oriented appropriately with regards to the leading robot, then the entire formation will have the proper orientation.

Additionally, it is easy to add functionality to the system. The behaviors themselves are easily modifiable. For example, the standard Go-To behavior goes forward to a destination, but if you want to return to the original position, the robot turns around 180 degrees and returns to the starting position. However, for the simple one-dimensional testing, it was useful to have the robots simply travel back and forth without turning around. A simple adjustment to the system was all that was required and then it was possible to use this testing feature.

4.5 The Overall Control Function

In order to control the formation with the vectors from the behaviors, it was necessary to create a controlling vector that is responsible for calculating the vector sum

and then moving the robots. This function also utilizes the gain factors that determine the importance of any one facet of the system. Since the primary purpose of this function is to calculate the vector sum of the behaviors active in the system, it is very simple. For more information regarding the controlling function, see Appendix B.

4.6 Getting into Formation

The one problem in the system that was not solved with a behavior is the problem of getting into the formation. For example, assume that the robots are scattered randomly about the room with little or no awareness of each other. To begin using the formation application, the robots first need to get into the proper orientation. To do this, our system uses the assignment algorithm. This well-defined algorithm is used to assign a number of items to the same number of positions by finding a minimum cost solution for the system. The system uses the distance formula as the weight factor to determine the best fit. Additionally, it implements Munkres' Assignment Algorithm (also known as the Hungarian Algorithm) described at the following website:

http://campus.murraystate.edu/academic/faculty/bob.pilgrim/445/algorithms_7.html[5]

For more information and a detailed description of the Hungarian Assignment Algorithm, refer to Appendix C.

The system will need to determine where all of the other robots are in the room and form a map in order to determine the distances to each other and to each position in the desired formation. In order to accomplish this, the function will need both the ranging and the angle of arrival data from the Ultra Wideband units. However, since the angle of arrival was not incorporated into the system, the project was unable to implement the ability to get into formation. Currently, the user will have to start the robots in their proper locations during setup and initialization of the application.

4.7 ARIA

ActivMedia Robotics Interface for Application or ARIA is the "robot control application-programming interface for ActivMedia Robotics' line of intelligent mobile robots"[6]. ARIA is written in C++ and works with both Linux systems and Windows. It

provides the functionality for connecting to the robot or the provided simulator, as well as managing the various sensors that can be implemented on the robots.

ARIA provides functions for direct motion control, such as go forward 2 meters, as well as functions for behavior based motion control. Behaviors in ARIA are known as actions. The action system is priority based so the action with the highest behavior gets to execute first. ARIA has several basic built-in actions, such as the Go-To function mentioned above. However, it is easy to create new actions or modify old ones.

ARIA has a cycle time of 100 milliseconds. In one cycle, each action is executed and the new values for speed and rotational angle are calculated. For more on ARIA and actions, refer to the Aria Reference Manual which can be found at http://robots.activmedia.com/ or look at Appendix B for action examples.

5. Graphical User Interface (GUI)

The main goal of the graphical user interface was to provide aesthetically pleasing and easy to use software. Via the GUI a user would be able to control the robot formation without physically touching the robots.

5.1 Software Tools and Components

To create the GUI, there were a few different technologies that could be used effectively. The first thing taken into consideration was which programming language to use. It was much easier to use C++ or a similar language to keep in sync with the ARIA software, as opposed to using some other language. One possible option to accomplish this was Microsoft Visual Studio's Interdev which had graphical capabilities. We chose to use a webpage structure for our GUI. This made the interface easier to construct and access the database using SQL and Active Server Pages.

Each screen viewed by the user was constructed using the VBScript and HTML languages. Dreamweaver was used to create buttons, hyperlinks, and help in debugging the GUI. The database was created using MySQL database server and accessed via Active Server Pages (ASP). All the laptops ran either Microsoft Windows 98 or 2000 and so given Windows' server capabilities it was easy to set up one of the laptops as the main unit. This laptop would be able to access the database, write to it, and transfer commands to the formation code.

We chose to implement a database to store information about the formation because it was a good way to maintain potentially large amounts of information which could be easily accessed. MySQL[7] is a program that allows you to quickly create a database and can interface with Windows' server capabilities. The Active Server Pages will send information to the database, which will later be retrieved by the formation code. There are tables pertaining to formation as well as formation movement, each of which currently contain rows to allow information for up to three robots. Depicted in Figure 5-1 is what a portion of the formations table would look like.

newFlag	numOfRobots	distance1	distance2	distance3	distance4	angle1	angle2	angle3	angle4
1	2	5	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	1	0	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	10	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	4	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 5-1 Excerpt from Formations Table

The first entry sets a flag value to '1' every time a new row is entered into the formation table so that the formation code will know when the table has been updated. The next column displays the number of robots chosen to be in the formation, followed by columns containing the distance to be maintained between robots, and the angle at which each robot needs to be in relation to one another. The angle feature is meant for future expansion of our design. There is also a table for formation movement which can be viewed in the Database Appendix D as well as a list of SQL commands.

5.2 Interface

When a user first enters the program they will see a screen with various formations displayed (Figure 5-2). Currently a user may only choose a formation with only two robots since we do not have the hardware to support a formation for a greater number of robots. Once the user has clicked on the number of robots and the type of

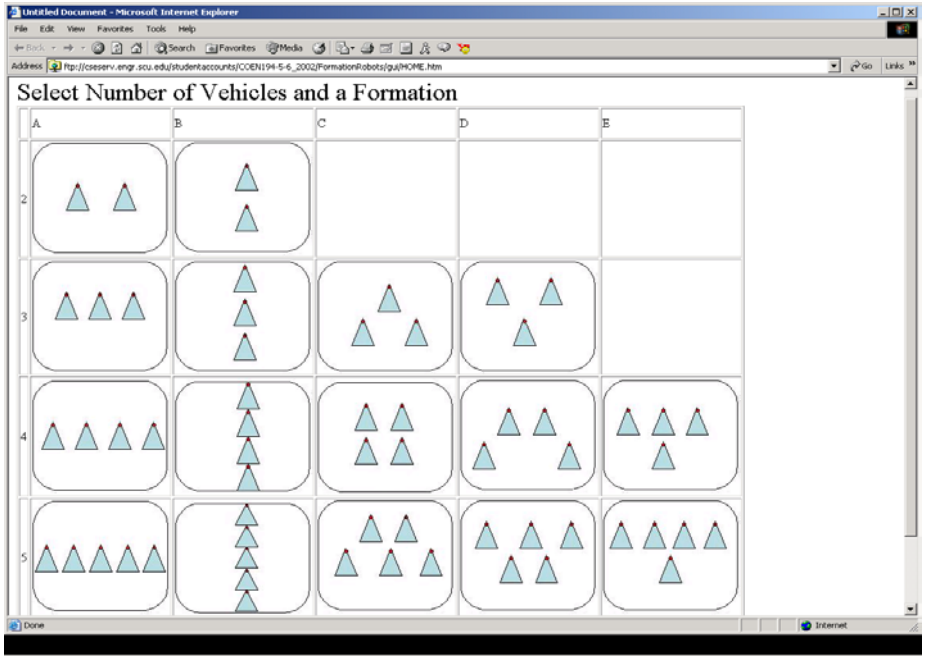


Figure 5-2 GUI: Choose a Formation Page

formation they want to use, they will be taken to a screen to verify their option.

Figure 5-3 depicts a screenshot of the current formation choice. At this point the formation type and number of robots should already have been sent to the database. The desired distance to be maintained (measured in feet) from robot to robot in the formation is to be entered into the appropriate text. Once this is done the user can click "OK" and continue onto the next screen of directions. The information which has been entered will be written to the formations table.

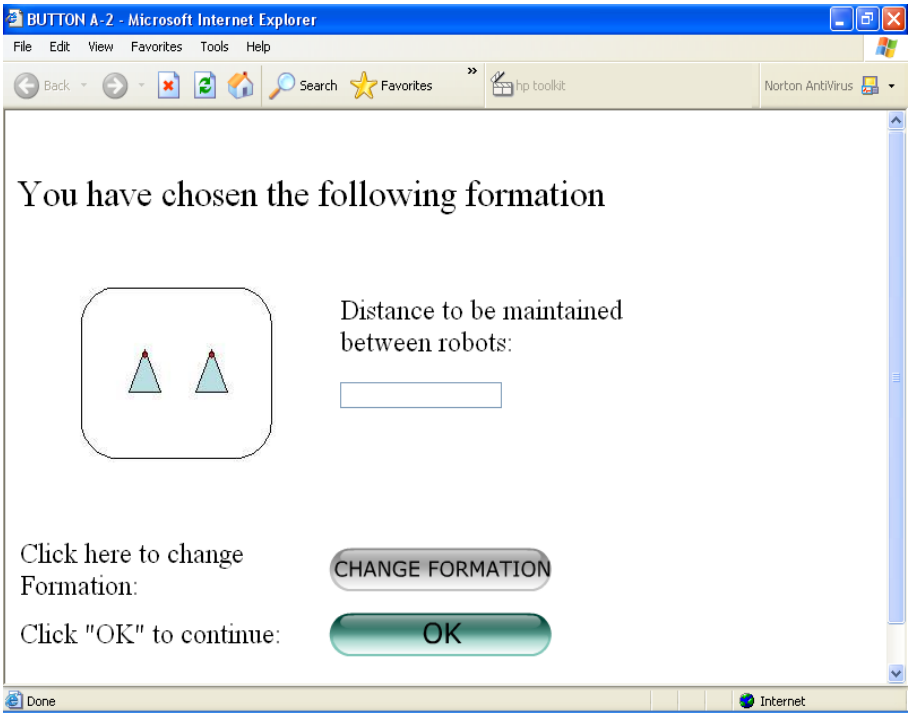


Figure 5-3 GUI: Select Distance Page

Once the user has chosen the distance to be maintained and hits "OK" the main screen will be displayed (Figure 5-4) At this point the current position should be displayed starting with '0' representing home position. The distance to be traveled can be entered into the "Desired Position" fields. This information will be sent to the movement table and every time new data is entered, the formation code will be alerted and will take in the new parameters.

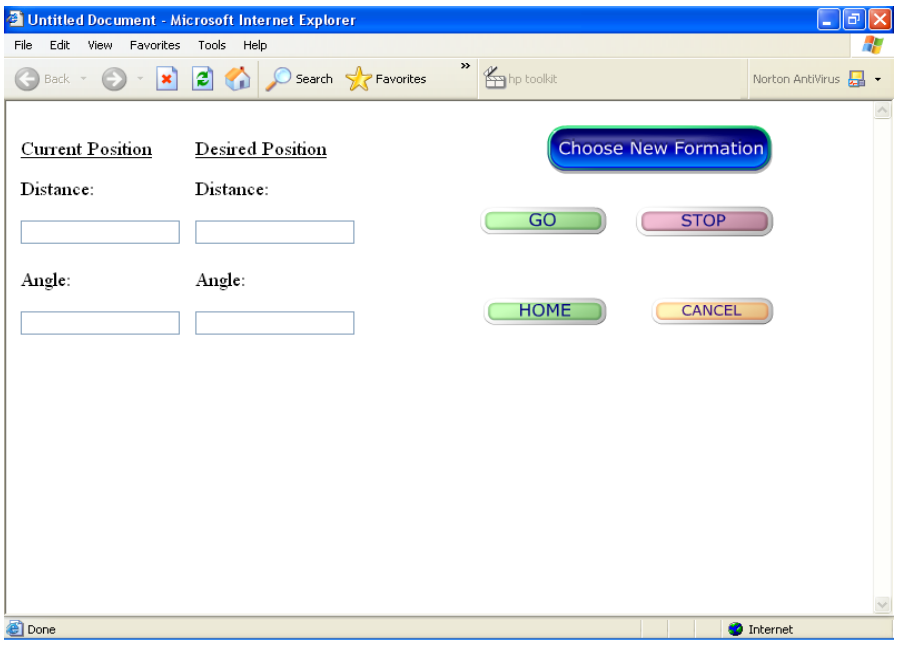


Figure 5-4 GUI: Interactive Page

At any time the user can go back and change their current formation, or they can start and stop the progress of the formation. The code for the various pages of GUI can be found in Appendix E and a more detailed User Manual can be found in Appendix G.

5.3 Future Work

The Graphical User Interface currently functions independently of the formation code. It has a limited sphere of control of the formation movement and still needs to be implemented to a fuller degree.

6. Integration and Test

6.1 Long-Range Testing

An immediate concern in our project was finding out how far the UWB units could be apart from each other and still pass information. A long-range test was performed in the Leavey Center at Santa Clara University. The scope of this experiment was to determine the maximum distance that the UWB units can be apart while still passing correct information. Figure 6-1 shows the experiment set up. In this test there was one stationary unit and one mobile unit. The mobile unit started at the same position as the stationary one. It was then moved in increments of five feet to a distance of 170 feet. Figure 6-2 shows the results of that test. You will notice that as the units moved further apart there were fewer readings. The receiver not being able to successfully get the acquisition header and data can explain this phenomenon. After extending the acquisition header these results were slightly improved.

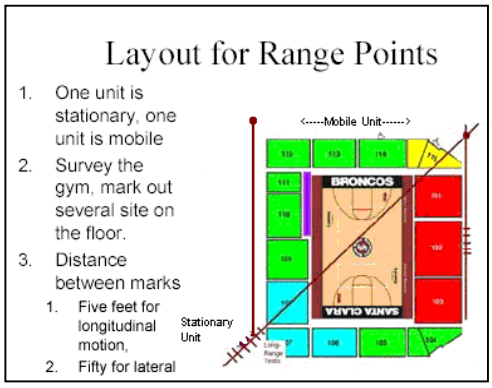

Layout for Range Points
1. One unit is stationary, one unit is mobile
2. Survey the gym, mark out several site on the floor.
3. Distance between marks
1. Five feet for longitudinal motion,
2. Fifty for lateral
<-----Mobile Unit------>
Stationary Unit
BRONCOS
SANTA CLARA

Figure 6-1 Test Layout

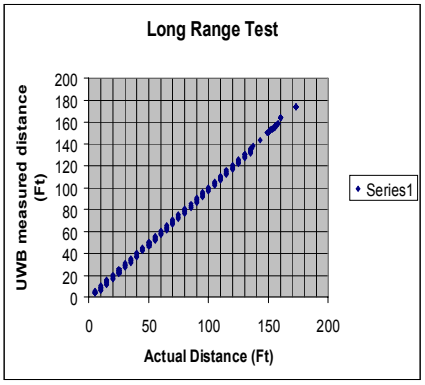


Figure 6-2 Long Range Results

6.2 Formation Testing

The distance test was design to give us an idea of the transients associated with system response. Two one-dimensional tests were performed. In both cases there was a lead and a follow robot. The lead robot was programmed to move forward and backward. The follow robot was programmed to follow the lead robot keeping a distance of seven feet.

Figure 6-3 shows the first set of results. This is a graph of the percent of error in the distance over a sample period. The curve shown here represents a response error.

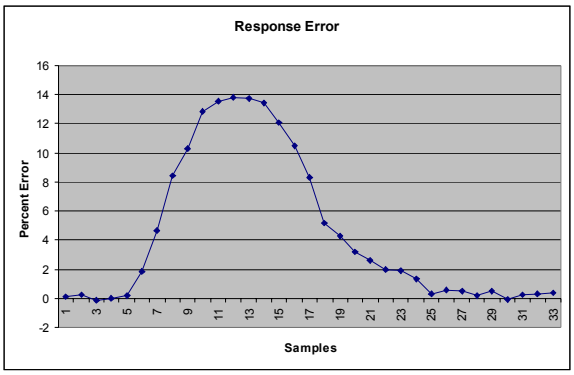


Figure 6-3 No Wall Test Results

That is, when the lead robot begins to move it takes the follow robot a certain amount of response time to react to changing distance. In essence, the lead robot will have moved a little before the follow robot realizes that it needs to start moving. Notice that after about 25 samples the graph oscillates around zero percent error. This happens when the follow robot reacts to the distance difference, catches up, and is able to reach a more steady state of maintaining the distance from the lead robot.

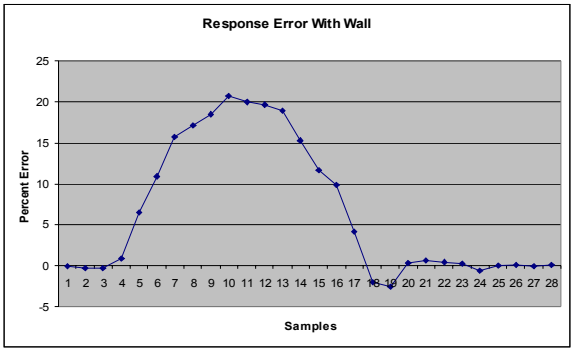


Figure 6-4 With Wall Test Results

As stated in section 3.1.4UWB is able to go through most barriers and does not require line of sight. To test this, a thin metal wall was placed in between the two UWB units. Figure 6-4 shows the results of this thru wall test. When comparing the two test results, with wall and without wall, we see that the response error is slightly better without the wall (Figure 6-5). There is about a five percent increase in response error when the thin wall is added. This is an expected result because the equipment is not perfect.

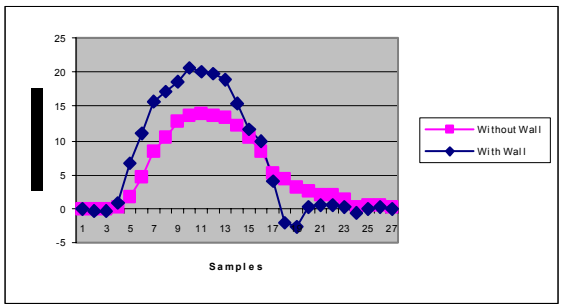


Figure 6-5 Wall vs. No Wall

7. Professional Issues

7.1 Social

Communities on Earth are continuously expanding, causing a greater need to explore options outside of our planet; for example, Mars. With the capabilities of the completely autonomous Formation Robots, we could explore and map the terrain of any unknown area without the loss of human life. One major problem could arise from our project. The problem follows the science fiction based theory, where giving more intelligence to computerized devices could drastically change the outcome of human kind.

7.2 Political

Our project had no intentions of having any political effect on the community. On the other hand, there is only one potential impact that our group could see as being an issue. In working with Lockheed Martin our Formation Robots design could be used for future military combat. This potential for combat goes against past protests by Santa Clara students and This the Santa Clara University Jesuit code.

7.3 Economic

Our project had very few economic hurdles to conquer. First off, most of our equipment was purchased by the SCU Robotic Department or on loan from Lockheed Martin (UWB). When economic considerations arose during the first stages of our project, we received money from the Engineering Department for potential involvement with the outside educational contributions.

7.4 Health and Safety

The only health issue related to our project may come in the form of electromagnetic radiation from the wireless communication devices needed in our system of robots. Ultra Wide Band is the only wireless communication device that may emit any sort of electromagnetic radiation. Due to the fact that the signals sent and received by the UWB units are low power, relative to analogous wireless communication devices, the

electromagnetic radiation is of little or no concern in terms of personal or environmental health.

As discussed earlier in the UWB section, UWB does not interfere with narrow band frequencies due to its modulation scheme. This is because UWB is spread over two or more gigahertz so that the power of the signal is not high at any one specific frequency. This implies that other channels, such as radio and emergency, will not be affected and can continue to run the same as always.

7.5 Manufacturability

This project is very specialized to certain situations. Each individual application may be a little bit different and the robots/control unit may have a different uses in various situations. Thus it would be difficult to manufacture this product. The term product, in fact, doesn't really apply to our project. The Formation Robots project is more of a research and design type of project. We are not building a product, but instead are attempting to put together other products in a useful manner.

7.6 Sustainability

The idea behind this project will continue to be used, transformed, and then reused many times over in the future. Robotic systems are such a big part of the continuing growth of our world's technology. We like to view our project as one of many stepping stones in a developing corner of technology.

7.7 Environmental Impact

Currently our project does not pose an environmental threat. It is fully operational via electrical power and so does not burn any gas or oil. The only possible problem could be the disposal of the batteries, but since they are rechargeable that is not a high concern. Not all parts that make up the system are biodegradable. Additionally, there is nothing that is emitted during operation that calls for any worries related to the environment.

7.8 Usability

In the system's current state, it is fairly easy to use and a new user should be able to learn the necessary functionality and maintenance of the formation by reading the manual or being taught by someone who knows the technology. The basic knowledge necessary to drive the formation should take about 5 or 10 minutes to learn. The actual execution of the programs is straight forward with directions provided to the user on the screen. If the system is already set up, the user does not need to know anything about the robots or UWB provided they do not malfunction.

Potential problems for the user would most be problems connecting the UWB to the computer and possibly initializing them, since this portion requires the most hardware knowledge. The main disadvantage of the current system is that when receiving real time commands from a user, they need to hold one of the laptops connected via serial port to a robot. This is the most user unfriendly aspect, yet over all it is not much of an inconvenience since the user may set up a program and watch the system run completely autonomously.

Formation Robots is usable by anyone who wishes to command more than one robot at a time by giving directional commands to one only robot. It does not take a lot of study to learn the rudimentary basics necessary to drive of the formation as long as someone knowledgeable with the system takes care of the maintenance. If the system were on the market or used in research the appropriate technical support would be provided.

7.9 Lifelong Learning

Lifelong learning requires that a person continue to expand his or her knowledge by researching and learning new things. Throughout the process of this project, our group practiced the skills that will help us learn new things in the future. For example, we were required to research different algorithms and methods to control the formation that are being studied in other research labs. Additionally, we had to learn new technologies such as new programming languages, new software, and new hardware. The process of learning new skills will be invaluable in our future careers.

Additionally, this project forced the members of our group to practice our communication skills. We had to communicate ideas to each other, our advisors, and others who were involved with the project. This is an important skill because in order to continue learning new things, a person needs to able to understand new concepts and communicate that new understanding to others. Therefore, this important teamwork skill will be very beneficial in future learning experiences.

7.10 Compassion

Although it was not originally a goal or motivation for this project, the various ways that the project results could be used to help others illustrate some degree of compassion. For example, a formation of robots could be used to help explore a disaster a rea that is unsafe for rescue workers. Clearly such motivation demonstrates a desire to relieve the suffering of others.

8. Conclusion

8.1 Summary

Formation Robots has completed the goals in which were established at the beginning of the project. We have a working prototype of a formation of two robots with one dimensional movement capabilities. The formation is able to avoid obstacles to a certain degree and can operate fully autonomously if desired. UWB units have been successfully used to maintain a given distance from robot to robot.

Although a lot of groundwork has established over the duration of the year, there is still much that can be done to improve the system. Angle of arrival can be implemented using UWB so that the formation can have three-dimensional capabilities. There are many areas in which the system can be improved upon. However, the necessary foundations have been laid for future research and design.

8.2 Contributions

Formation Robots is the first senior design project at Santa Clara University that has explored the possibilities of formation control. We were able to successfully control two robots in a one-dimensional formation. Some of these algorithms could be the building blocks for future senior design projects.

Without the help of industry it would have been rather difficult to gain all of the necessary equipment. Through working with Lockheed Martin, in particular Bob Dougherty, we helped to strengthen a University-Industry relationship. The goal was to share our findings with Lockheed Martin in return for the usage of their UWB technology. As a result of the mutual endeavor, UWB technology will continue to be integrated into the Santa Clara University Robotics Program.

8.3 Future Extensions

This project has a lot of potential for expansion. Logically, the next step for this project is to implement the next generation of Ultra Wideband technology. The new technology will have the capability to transmit the angle of arrival data that would allow for two-dimensional control of the formation, as well as more complex formations. Once the ability for two-dimensional control has been implemented, it will be possible to

experiment with three or more robots in formation. After this point, it would be useful to test the behavioral controls by adjusting the various gain factors and then to compare the behavioral algorithm to other control possibilities. Beyond this point, future expansion may include application specific development and testing as well as testing technologies other than Ultra Wideband.

8.4 Lessons Learned

Over the course of the year we have not only learned to apply our cumulative knowledge to building a control system, but we have also gotten a glimpse into issues of the real world. Once a project's scope is bigger than something one person can accomplish, it becomes necessary to some times rely on the support of others. While technical as well as mental support is helpful, there are times where it may not come in time and a backup plan is necessary. We also found that prototypes could be very useful and may have helped to find problems earlier on.

Possibly one of the most important aspects of group design that many people tend to overlook is group dynamics. When everyone in the team gets along and there is a relaxed friendly atmosphere it is much easier to get work done and keep everyone happy. Work no longer becomes a chore but something to be looked forward to, and at its worst tolerated since the company is always good. We found the keys to a successful senior design project to be an interesting and motivating project, support from our advisors above and beyond their duties, and unique group dynamics.

Appendix A - Compass Code

BASIC Code

```
'**      I2C       Routines for the Basic       Stamp           **
'**        using the       CMPS01/CMPS03 CompassModule          **
'**                                                             **
'**     This Code has been Tested on BS2 and       BS2p         **
'**  It should work equally well on the BS2e and       BS2sx    **
'**                                                             **
'*************************************************************

SDA con       8         ' I2C data
SCL con       9         ' I2C clock
SDAin var in8
SDAout var       out8   ' To change the pins used, alter these 5 lines
DAdir var       dir8    ' The 4 SDA numbers must be the same, of course

loop var       byte     ' just a looping counter
I2cBuf var       byte   ' I2c read/write buffer
I2cAddr var       byte  ' Address of I2C device
I2cReg var       byte   ' Register number within I2C device
I2cData var       word  ' Data to read/write
I2cAck var       bit    ' Acknowledge bit


Main:
I2cAddr =       $c0     ' CMPS01/03 Compass module address
I2cReg =       1        ' Bearing as 0-255 (BRAD)
gosub I2cByteRead
debug 2,0,0, "Compass Bearing (0-255 BRAD) ", dec3 I2cData
I2cReg =       2        ' Bearing as 0-359.9 degrees
gosub I2cWordRead
debug 2,0,1, "Compass Bearing (0-359 Degrees ", dec3 I2cData/10

goto main

'-------------------------------------------------------------------------
---------------------
' I2C subroutines follow
'-------------------------------------------------------------------------
---------------------

I2cByteWrite:           ' writes I2cData.lowbyte to I2cReg at I2cAddr
gosub I2cStart
I2cBuf = I2cAddr
gosub       I2cOutByte  ' send device address
I2cBuf = I2cReg
gosub       I2cOutByte  ' send register number
I2cBuf = I2cData.lowbyte
gosub       I2cOutByte   ' send the data
gosub I2cStop
return

I2cWordWrite:            ' writes I2cData to I2cReg at I2cAddr
gosub I2cStart
```

```
I2cBuf = I2cAddr
gosub       I2cOutByte   ' send device address
I2cBuf = I2cReg
gosub       I2cOutByte   ' send register number
I2cBuf = I2cData.highbyte
gosub       I2cOutByte    ' send the data - high byte
I2cBuf = I2cData.lowbyte
gosub       I2cOutByte    ' send the data - low byte
gosub I2cStop
return

I2CByteRead:
gosub I2cStart
I2cBuf = I2cAddr
gosub       I2cOutByte    ' send device address
I2cBuf = I2cReg
gosub       I2cOutByte    ' send register number
gosub       I2cStart      ' repeated start
I2cBuf = I2cAddr | 1
gosub       I2cOutByte    ' send device address (with read set)
I2cAck =       0          ' send Nak
gosub I2cInByte
I2cData.lowbyte = I2cBuf  ' read the data
I2cData.highbyte = 0
gosub I2cStop
return

I2CWordRead:
gosub I2cStart
I2cBuf = I2cAddr
gosub       I2cOutByte    ' send device address
I2cBuf = I2cReg
gosub       I2cOutByte    ' send register number
gosub       I2cStart      ' repeated start
I2cBuf = I2cAddr | 1
I2cAck =       1          ' send Ack
gosub       I2cOutByte    ' send device address (with read set)
gosub I2cInByte
I2cData.highbyte =I2cBuf  ' read the data
I2cAck =       0          ' send Nak
gosub I2cInByte
I2cData.lowbyte = I2cBuf
gosub I2cStop
return

I2cOutByte:
shiftout SDA, SCL, MSBFIRST, [I2cBuf]
input SDA
high       SCL            ' clock in the ack' bit
low SCL
return

I2cInByte:
shiftin SDA, SCL, MSBPRE, [I2cBuf]
SDAout = 0
SDAdir = I2cAck
high       SCL            ' clock out the ack' bit
low SCL
input SDA
return
```

```
I2cStart                ' I2C start bit sequence
high SDA
high SCL
low SDA
low SCL
return

I2cStop:                ' I2C stop bit sequence
low SDA
high SCL
high SDA
return
```

Appendix B - Control Code

B.1 Database Access Code

```
/*
custom3.h
Definition for custom3
*/

#include <iostream>
#include <vector>
#include <sqlplus.hh>
#include <custom.hh>
#include "util.hh"

#include "formationClass.h"

int getNewest();
formationClass getFormation(int row);

/*
Custom3.cpp
This file, based on the mysql++ tutorial provides the
primary interface between the C++ code and the user
database, it grabs the database information and creates
a formation out of it.
*/
#include "custom3.h"

sql_create_11 (formations,            // struct name,
               1,11,
                     int, count,
               int, newFlag,     // type, id
               int, numOfRobots,
               double, distance1,
                     double, distance2,
                     double, distance3,
                     double, distance4,
                     double, angle1,
                     double, angle2,
                     double, angle3,
                     double, angle4)


// Create the formation of robots
formation getFormation(int row)
{
      cchar* myDB = "FormationRobots";
      Connection con(myDB);
      Query query = con.query();

      query << "select * from formations where count = '" << row "'";

      vector < stock > res;
    query.storein (res);
```

```
      formations row = res[0];

      // This method needs to be improved to allow for
      // more than 2 robots
      coordinate positions[numOfRobots + 1];
      coordinate myCoordinate();
      positions[0] = myCoordinate;
      positions[1] = coordinate(distance1, distance2);
      positions[2] = coordinate(distance2, distance3);
      positions[3] = coordinate(distance3, distance4);


      formation myFormation(row.numOfRobots, positions);

      return myFormation;
}

// Get the newest formation information
int getNewest()
{
  try { // its in one big try block

      int newestRow = 0;
    cchar* myDB = "FormationRobots";
      Connection con(myDB);
      Query query = con.query();

      query << "select * from formations where newFlag = '1'";

      Result res = query.store();
    if (res.empty())
      throw BadQuery("Nothing New");
    // here we are testing if the query was successful, if not throw a
bad query

      int size = res.size();

      for(int i = 0; i < size; i++)
      {
            formations row = res[i];
            if(row.newFlag == 1)
            {
                  newestRow = row.count;

                  formations row2 = row;
                  // Now we need to create a copy so that the replace
query knows
                  // what the original values are.

                  row.newFlag = 0; // now change item

                  query.update(row2, row);
                  // form the query to replace the row
                  // the table name is the name of the struct by
default
                  cout << "Query : " << query.preview() << endl;
```

```
                // show the query about to be executed
                query.execute();
                // execute a query that does not return a result set
            } // end if
      } // end for loop

    return newestRow;

  } catch (BadQuery er) {
    cerr << "Error " <<  endl;
    return -1;
  } catch (BadConversion er) {
    return -1;
  }
}


/*
SimpleFollow.cpp
This is the implementation of the following robot behavior
for maintain distances.  It contains the main() that controls
the following robot.  It also sets up the robot interface.
It is almost the same as the SimpleFollow provided in the
following robot section, but with changes to allow input to
come from the database rather than the user.
*/

#include "Aria.h"
#include "PADRequest.h"
#include <stdio.h>
#include <iostream.h>
#include "ActionMaintainDistance.h"
#include "PADFunctions.h"
#include "custom3.h"

int main(void)
{
  double goalRange;
  int inFront = 0;
  bool frontFlag = false;
  bool simulator;
  formationClass myFormation();


      // Get the formation information
      int row = getNewest();

      if(row > 0)
      {
            myFormation = getFormation(row);
      }

      coordinate myCoordinate = myFormation.getPosition(2);
      goalRange = myCoordinate.getX();

    //Set up Ultra Wide Band
      long int rate;
```

```
      PADRequest* PADComm = initializePAD();
      rate = PADComm->RequestRateGet();
    PADComm->VerbosityReadSet(0);
      PADComm->VerbosityWriteSet(0);


  //Set up Pioneer Robot
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // Make a key handler, so that escape will shut down the program
  // cleanly
  ArKeyHandler keyHandler;

  // Add the key handler to Aria so other things can find it
  Aria::setKeyHandler(&keyHandler);

  // Attach the key handler to a robot now, so that it actually gets
  // some processing time so it can work, this will also make escape
exit
  robot.attachKeyHandler(&keyHandler);

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
      simulator = true;
  }
  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
    // device

    // modify the next line if you're not using the first serial port
    // to talk to your robot
    serConn.setPort();
    printf(
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
```

```
      simulator = false;
  }


  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  // Get the user defined parameters for the system
  cout << "Current range is: " << getRange (PADComm, simulator, 0, 0,
false) << endl;

  // If the robot is in front, then to move closer to the other robot
  //  then this robot needs to move backward rather than forward
  if(inFront == 1)
        frontFlag = true;

  // the behaviors from above, and a stallRecover behavior that uses
defaults
  ArActionAvoidFront avoid;
  ArActionStallRecover recover;
  ActionMaintainDistance maintainDistance(goalRange, PADComm,
frontFlag, simulator);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
  robot.addAction(&recover, 100);
  robot.addAction(&maintainDistance, 50);
  //robot.addAction(&avoid, 45);

  // run the robot, the true here is to exit if it loses connection
  robot.run(true);

  // now just shutdown and go away
  Aria::shutdown();
  return 0;

}
```

B.2 Lead Robot Implementation

```
/*
SimpleAvoid.cpp
This is the actual implementation that is currently used
```

```
on the leading robots.  It includes the primary main() of
the system.  It also sets up the robot to receive commands
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "ActionGo.h"

int main(void)
{

  double goalX;
  double goalY;
  double goalTh;
  ArPose goalPosition;
  ArPose currentPosition;

  const double avoidWeight = 1.0;
  const double goToWeight = 1.0;

  //Set up Pioneer Robot
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
  }
  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
    // device

    // modify the next line if you're not using the first serial port
    // to talk to your robot
    serConn.setPort();
    printf(
```

```
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
  }


  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  coordinate coord1 = coordinate(0,0);
  coordinate coord2 = coordinate(0,500);
  coordinate myPositions[2] = {coord1, coord2};

  currentPosition = robot.getPose();
  cout << "Current X: " << currentPosition.getX() << endl;
  cout << "Current Y: " << currentPosition.getY() << endl;

  cout << "Enter the desired x coordinate:" << endl;
  cin >> goalX;
  cout << "Enter the desired y coordinate:" << endl;
  cin >> goalY;
  goalTh = 0;

  goalPosition.setPose(goalX, goalY, goalTh);

  // the behaviors from above, and a stallRecover behavior that uses
defaults
  completeVector control;
  ActionAvoidObstacle avoid(myPositions, 2, avoidWeight, 2, &control);
  ArActionStallRecover recover;
  ActionGo go(goalPosition, 100, 500, goToWeight, 150, 7, &control);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
  robot.addAction(&recover, 100);
  robot.addAction(&go, 30);
  robot.addAction(&avoid, 30);
  robot.addAction(&control, 90);

  // run the robot, the true here is to exit if it loses connection
  robot.runAsync(false);

  while(true)
  {
      while(!go.haveAchievedGoal())
```

```
      {
            currentPosition = robot.getPose();
            cout << "Current X: " << currentPosition.getX() << endl;
            cout << "Current Y: " << currentPosition.getY() << endl;
            ArUtil::sleep(1000);
      }

      avoid.goalDone();
      cout << "Acheived Goal!" << endl;

      cout << "Enter the desired x coordinate:" << endl;
      cin >> goalX;
      cout << "Enter the desired y coordinate:" << endl;
      cin >> goalY;

      goalPosition.setPose(goalX, goalY, goalTh);
      go.setGoal(goalPosition);
      avoid.newGoal();
      control.restart();
  }

  // now just shutdown and go away
  Aria::shutdown();
  return 0;

}


/*
Definition for the completeVector class
*/

#include "Aria.h"
#include "BuildObstacleMap.h"
#include <stdio.h>
#include <iostream.h>

class completeVector: public ArAction
{
public:
  // constructor, sets myDistance, robot, and the PAD
  completeVector(void);
  // destructor, its just empty, we don't need to do anything
  virtual ~completeVector(void) {};
  // set the robot
  void setRobot(ArRobot *robot);
  // fire, this is what the resolver calls to figure out what this
action wants
  virtual ArActionDesired *fire(ArActionDesired currentDesired);
  // get velocity
  double getVelocity();
  // get angle
  double getAngle();
  // add to the velocity
  void addVelocity(double velocity, double weight);
  // add to the angle
  void addAngle(double angle, double weight);
```

```
  // set the velocity, primarily used for stopping
  void setVelocity(double velocity);
  // subtract a velocity
  void subVeocity(double velocity, double weight);
  // subtract from the angle
  void subAngle(double angle, double weight);
  // add to the angle with a delta
  void addDeltaAngle(double angle, double weight);
  // reset the stop variable
  void restart();
protected:
  // what the action wants to do
  ArActionDesired myDesired;
  // the velocity
  double myVelocity;
  // the angle
  double myAngle;
  // stop variable
  bool myStop;
};


/*
completeVector.cpp
The complete vector is the controlling program in the system.
It controls the movements of the robot by creating the vector
sum of all of the behaviors in the system.
*/

#include "completeVector.h"
#include <ariaUtil.h>

const double myMaxSpeed = 500;

/*
  This is the constructor
*/
completeVector::completeVector() :
  ArAction("Obstacle")
{
      myAngle = 0;
      myVelocity = 0;
      myStop = false;

    setNextArgument(ArArg("Angle", &myAngle, "The angle the bot should
face."));
    setNextArgument(ArArg("Velocity", &myVelocity, "The desired
velocity of the robot"));
}

/*
  Sets the myRobot pointer (all setRobot overloaded functions must do
this),
  finds the sonar device from the robot, and if the sonar isn't there,
  then it deactivates itself.
*/
void completeVector::setRobot(ArRobot *robot)
```

```
{
  myRobot = robot;
}

/*
  This fire is the whole point of the action.
*/
ArActionDesired *completeVector::fire(ArActionDesired currentDesired)
{
      // reset the actionDesired (must be done)
      myDesired.reset();

      myDesired.setDeltaHeading(myAngle);

    // now set the velocity
    myDesired.setVel(myVelocity);

      // return a pointer to the actionDesired, so resolver knows what
to do
      return &myDesired;
}

void completeVector::addVelocity(double velocity, double weight)
{
      if(!myStop)
      {
            myVelocity = (velocity * weight) + myVelocity;
            if(velocity > myMaxSpeed)
                  myVelocity = myMaxSpeed;
      }
}

void completeVector::addAngle(double angle, double weight)
{
      if(!myStop)
            myAngle = (angle * weight) + myAngle;
}

void completeVector::setVelocity(double velocity)
{
      if(!myStop)
      {
            myVelocity = velocity;
            if(velocity == 0)
                  myStop = true;
      }
}

void completeVector::subVeocity(double velocity, double weight)
{
      if(!myStop)
      {
            myVelocity = myVelocity - (velocity * weight);
            if(myVelocity < -myMaxSpeed)
                  myVelocity = -myMaxSpeed;
      }
}
```

```
void completeVector::subAngle(double angle, double weight)
{
      if(!myStop)
            myAngle = myAngle - (angle * weight);
}

double completeVector::getVelocity()
{
      return myVelocity;
}

double completeVector::getAngle()
{
      return myAngle;
}

void completeVector::addDeltaAngle(double angle, double weight)
{
      if(!myStop)
      {
            double difference = myAngle - (angle * weight);
            myAngle = myAngle + difference;
      }
}

void completeVector::restart()
{
      myStop = false;
}
```

B.3 The Go-To Behavior Implementation and Associated Files

```
/*
Definition for the ActionGo function
*/

#include "ariaTypedefs.h"
#include "ariaUtil.h"
#include "ArAction.h"
#include "ArExport.h"
#include "ariaOSDef.h"
#include "ArRobot.h"
#include "ActionAvoidObstacle.h"

class ActionGo : public ArAction
{
  public:
      ActionGo::ActionGo(ArPose goal, double closeDist, double speed,
double myWeight,
                              double speedToTurnAt, double turnAmount,
completeVector* myControl);
      virtual ~ActionGo(void);
      bool ActionGo::haveAchievedGoal(void);
      void ActionGo::cancelGoal(void);
      void ActionGo::setGoal(ArPose goal);
```

```
      virtual ArActionDesired *fire(ArActionDesired currentDesired);
  protected:
      int myDirectionToTurn;
      bool myPrinting;
      double myCloseDist;
      double mySpeed;
      double mySpeedToTurnAt;
      double myTurnAmount;
      completeVector* control;
      ArPose myGoal;
    double myCurTurnDir;
    ArActionDesired myDesired;
    bool myTurnedBack;
    ArPose myOldGoal;
      double myWeight;

    enum State
      {
            STATE_NO_GOAL,
            STATE_ACHIEVED_GOAL,
            STATE_GOING_TO_GOAL
      };
      State myState;
};


/*
ActionGo.cpp
This is the function that implements the Go-To behavior.
It is primarily taken from ActivMedia's example, but
with a few minor modifications
*/


/*
ActivMedia Robotics Interface for Applications (ARIA)
Copyright (C) 2002, ActivMedia Robotics, LLC


     This program is free software; you can redistribute it and/or
modify
     it under the terms of the GNU General Public License as published
by
     the Free Software Foundation; either version 2 of the License, or
     (at your option) any later version.

     This program is distributed in the hope that it will be useful,
     but WITHOUT ANY WARRANTY; without even the implied warranty of
     MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
     GNU General Public License for more details.

     You should have received a copy of the GNU General Public License
     along with this program; if not, write to the Free Software
     Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-
1307  USA

If you wish to redistribute ARIA under different terms, contact
```

```
ActivMedia Robotics for information about a commercial version of ARIA
at
robots@activmedia.com or
ActivMedia Robotics, 44 Concord Street, Peterborough, NH 03458; 603-
924-9100

*/

#include "ariaOSDef.h"
#include "ActionGo.h"
#include "ArRobot.h"

ActionGo::ActionGo(ArPose goal, double closeDist, double speed, double
weight,
                               double speedToTurnAt, double turnAmount,
completeVector* myControl):
  ArAction("Go")
{
  myDirectionToTurn = 1;
  myPrinting = false;
  myWeight = weight;

  //setNextArgument(ArArg("goal", &myGoal, "ArPose to go to.
(ArPose)"));
  setGoal(goal);

  setNextArgument(ArArg("close dist", &myCloseDist,
                  "Distance that is close enough to goal. (mm)"));
  myCloseDist = closeDist;

  setNextArgument(ArArg("speed", &mySpeed,
                  "Speed to travel to goal at. (mm/sec)"));
  mySpeed = speed;

  setNextArgument(ArArg("speed to turn at", &mySpeedToTurnAt,
                  "Speed to start obstacle avoiding at (mm/sec)"));
  mySpeedToTurnAt = speedToTurnAt;

  setNextArgument(ArArg("amount to turn", &myTurnAmount,
                  "Amount to turn when avoiding (deg)"));
  myTurnAmount = turnAmount;

  // Had to add the completeVector to allow us to use our
  // controlling function
  control = myControl;
}

ActionGo::~ActionGo(void)
{}

bool ActionGo::haveAchievedGoal(void)
{
  if (myState == STATE_ACHIEVED_GOAL)
    return true;
  else
    return false;
}
```

```
void ActionGo::cancelGoal(void)
{
  myState = STATE_NO_GOAL;
}

void ActionGo::setGoal(ArPose goal)
{
  myState = STATE_GOING_TO_GOAL;
  myGoal = goal;
  myTurnedBack = false;
  myCurTurnDir = myDirectionToTurn;
  myOldGoal = myGoal;
}

ArActionDesired *ActionGo::fire(ArActionDesired currentDesired)
{
  double angle;
  double dist;
  double vel;

  if (myGoal.findDistanceTo(myOldGoal) > 5)
    setGoal(myGoal);

  // if we're there we don't do anything
  if (myState == STATE_ACHIEVED_GOAL || myState == STATE_NO_GOAL)
    return NULL;

  dist = myRobot->getPose().findDistanceTo(myGoal);

  // if we are close enough and slow, stop moving and return
  if (dist < myCloseDist && fabs(myRobot->getVel() < 5))
  {
    myState = STATE_ACHIEVED_GOAL;
      control->setVelocity(0);
      myDesired.setVel(0);
    return &myDesired;
  }

  // see where we want to point
  angle = myRobot->getPose().findAngleTo(myGoal);

  if (ArMath::fabs(ArMath::subAngle(angle, myRobot->getTh())) > 120)
  {
    myCurTurnDir *= -1;
  }

  // see if somethings in front of us
  if (currentDesired.getMaxVelStrength() > 0 &&
      currentDesired.getMaxVel() < mySpeedToTurnAt)
  {
        control->addDeltaAngle(myTurnAmount * myCurTurnDir, myWeight);
  }

  else
  {
    // see if we want to just point at the goal or not
```

```
    if (ArMath::fabs(ArMath::subAngle(angle,
            ArMath::addAngle(myTurnAmount * myCurTurnDir * -1,
            myRobot->getTh())))     > myTurnAmount/2)
    {
            control->addAngle(angle, myWeight);
      }

      else
    {
            control->addDeltaAngle(myTurnAmount * myCurTurnDir * -1,
myWeight);
      }
  } // end if currentDesired ...

  if (dist < myCloseDist && fabs(myRobot->getVel() < 5))
  {
    myState = STATE_ACHIEVED_GOAL;
      control->setVelocity(0);
      myDesired.setVel(0);
  }

  // if we're close, stop
  else if (dist < myCloseDist)
  {
        myState = STATE_ACHIEVED_GOAL;
        control->setVelocity(0);
        myDesired.setVel(0);
  }

  else
  {
    vel = sqrt(dist * 200 * 2);
    if (vel > mySpeed)
      vel = mySpeed;
      control->addVelocity(vel, myWeight);
      myDesired.setVel(myRobot->getVel());
  } // end if dist < myCloseDist

  // keep status quo for now and let the completeVector do the work
  //myDesired.setVel(myRobot->getVel());
  return &myDesired;
}


/*
Definition of ActionGo for lead1d
*/

#include "Aria.h"
#include <iostream.h>
#include <stdio.h>

class ActionGo : public ArAction
{
public:
  // constructor sets myStopDistance
  ActionGo(double Distance);
```

```
  // destructor, its just empty, we don't need to do anything
  virtual ~ActionGo(void) {};
  // fire, this is what the resolver calls to figure out what this
action wants
  virtual ArActionDesired *fire(ArActionDesired currentDesired);
  // sets the robot pointer, also gets the sonar device
  virtual void setRobot(ArRobot *robot);
  // change the value of distance
  void setDistance(double distance);
  // checks to see if the move has been completed
  bool isDone();
  double abs(double value);
protected:
  // this is to hold the sonar device form the robot
  ArRangeDevice *mySonar;
  // what the action wants to do
  ArActionDesired myDesired;
  // where we want to be
  double myDistance;
  // to know when we are done
  bool done;
  // to know if we are going backwards
  bool backwards;
};



/*
actionGo.cpp for lead1d
lead1d = lead one-dimensional for the leading robot.
This is a quick action that models the goTo behavior but
does not turn, it simply goes forward or backwards the
specified distance.  It allows for simple one-dimensional
Testing.
*/


#include "ActionGo.h"

ActionGo::ActionGo(double Distance) :
  ArAction("Go")
{
  mySonar = NULL;
  myDistance = Distance;
  setNextArgument(ArArg("distance", &myDistance, "Distance to go."));
  done = false;
}

void ActionGo::setRobot(ArRobot *robot)
{
  myRobot = robot;
  mySonar = myRobot->findRangeDevice("sonar");
  if (mySonar == NULL)
    deactivate();
}

void ActionGo::setDistance(double distance)
```

```
{
      myDistance = myRobot->getX() + distance;
      done = false;
}

bool ActionGo::isDone()
{
      return done;
}

/*
  This fire is the whole point of the action.
*/
ArActionDesired *ActionGo::fire(ArActionDesired currentDesired)
{
  double speed;
  double currentX;

  // reset the actionDesired (must be done)
  myDesired.reset();

  if(done)
  {
        myDesired.setVel(0);
        return &myDesired;
  }

  currentX = myRobot->getX();
  cout << "Current: " << currentX << endl;
  double diff = myDistance - currentX;
  if (abs(diff) > 1)
  {
    speed = .8 * diff;
      myDesired.setVel(speed);
  }

  // the range was less than the stop distance, so just stop
  else
  {
      done = true;
    myDesired.setVel(0);
  }

  // return a pointer to the actionDesired, so resolver knows what to
do
  return &myDesired;
}

double ActionGo::abs (double value)
{
      if(value < 0)
            return -value;
      else
            return value;
}

/*
```

```
lead1d.cpp
This is the implementation of the lead1d function.  It is
very similar to the simpleAvoid functionality but without
obstacle avoidance and implemented to work with the one-
dimensional tests.
*/

#include <ariaUtil.h>
#include <stdio.h>
#include <iostream.h>

#include "actionGo.h"

double askX();

int main(void)
{
  double goalX;

  /* Set up Pioneer Robot */
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // Make a key handler, so that escape will shut down the program
  // cleanly
  ArKeyHandler keyHandler;

  // Add the key handler to Aria so other things can find it
  Aria::setKeyHandler(&keyHandler);

  // Attach the key handler to a robot now, so that it actually gets
  // some processing time so it can work, this will also make escape
exit
  robot.attachKeyHandler(&keyHandler);

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
  }
```

```
  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
    // device

    // modify the next line if you're not using the first serial port
    // to talk to your robot
    serConn.setPort();
    printf(
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
  }

  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  // ask the user for input
  goalX = askX();

  // the behaviors from above, and a stallRecover behavior that uses
defaults
  ArActionAvoidFront avoid;
  ArActionStallRecover recover;
  ActionGo go(goalX);

  go.setRobot(&robot);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
  robot.addAction(&recover, 100);
  robot.addAction(&go, 60);
  //robot.addAction(&avoid, 55);

  // run the robot, the true here is to exit if it loses connection
  robot.runAsync(false);

  while(true)
  {
        ArUtil::sleep(1000);

        if(go.isDone())
                  go.setDistance(askX());
  }
```

```
  // now just shutdown and go away
  Aria::shutdown();
  return 0;

}

double askX()
{
      double goalX;
      cout << "Enter the desired distance:" << endl;
      cin >> goalX;
      return goalX;
}


/*
lead1d.cpp modified for back and forth
This is a modification of the lead1d program.  It
simply starts by moving forwards 2 meters and then
2 meters backwards.  It just does this until the
user stops the program.  This was written for primarily
demonstration purposes only.
*/

#include <ariaUtil.h>
#include <stdio.h>
#include <iostream.h>

#include "actionGo.h"

int main(void)
{
  double goDistance = 2000;
  double goBackDistance = -goDistance;
  double goalX;

  /* Set up Pioneer Robot */
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // Make a key handler, so that escape will shut down the program
  // cleanly
  ArKeyHandler keyHandler;

  // Add the key handler to Aria so other things can find it
  Aria::setKeyHandler(&keyHandler);
```

```
  // Attach the key handler to a robot now, so that it actually gets
  // some processing time so it can work, this will also make escape
exit
  robot.attachKeyHandler(&keyHandler);

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
  }

  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
    // device

    // modify the next line if you're not using the first serial port
    // to talk to your robot
    serConn.setPort();
    printf(
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
  }

  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  // the behaviors from above, and a stallRecover behavior that uses
defaults
  ArActionStallRecover recover;
  ActionGo go(goDistance);

  go.setRobot(&robot);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
```

```
  robot.addAction(&recover, 100);
  robot.addAction(&go, 60);

  // run the robot, the true here is to exit if it loses connection
  robot.runAsync(false);

  while(true)
  {
        ArUtil::sleep(1000);

        if(go.isDone())
        {
              ArUtil::sleep(5000);
              if((count % 2) == 0)
                  go.setDistance(goBackDistance);
              else
                  go.setDistance(goDistance);
        }
  }

  // now just shutdown and go away
  Aria::shutdown();
  return 0;

}
```

B.4 The Avoid Obstacle Behavior Implementation and Supporting Classes

```
/*
Definition of the ActionAvoidObstacle function
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "completeVector.h"

class ActionAvoidObstacle : public ArAction
{
public:
  // constructor, sets myDistance, robot, and the PAD
  ActionAvoidObstacle::ActionAvoidObstacle(coordinate positions[], int
numBots, double weight,
                                                                  int
myPosition, completeVector* control);
  // destructor, its just empty, we don't need to do anything
  virtual ~ActionAvoidObstacle(void) {};
  // fire, this is what the resolver calls to figure out what this
action wants
  virtual ArActionDesired *fire(ArActionDesired currentDesired);
  // sets the robot pointer, also gets the sonar device
  virtual void setRobot(ArRobot *robot);
  // see if obstacle is actually another robot
  bool ActionAvoidObstacle::isRobot(double angle);
  // absolute value
  double abs(double value);
```

```
  void ActionAvoidObstacle::goalDone();
  void ActionAvoidObstacle::newGoal();

protected:
  // this is to hold the sonar device form the robot
  ArRangeDevice *mySonar;
  // what the action wants to do
  ArActionDesired myDesired;
  // The formation the bots are maintaining
  formationClass myFormation;
  // The position in the formation for this robot
  int formationPosition;
  // The Obstacle Map for our robots
  BuildObstacleMap obstacles;
  // The number of robots in our formation
  int numRobots;
  // bool at goal
  bool goal;
  // The overall controlling vector
  completeVector* myControl;
  // The weight of this action
  double myWeight;
};


/*
ActionAvoidObstacle.cpp
Action Avoid Obstacle is the implementation of the Avoid Obstacles
behavior.  It is primarily used on the leader robot, but could
potentially be added to the control of any robot in the system.
*/

#include "ActionAvoidObstacle.h"
#include <ariaUtil.h>

const double warningRange = 2.0;
const char BEEP = '\a';
const double myMaxSpeed = 500;

/*
  This is the constructor
*/
ActionAvoidObstacle::ActionAvoidObstacle(coordinate positions[], int
numBots, double weight,
                                                                  int
myPosition, completeVector* control) :
  ArAction("Obstacle")
{
      mySonar = NULL;
      formationClass myFormation = formationClass(numBots, positions);
      formationPosition = myPosition;
      numRobots = numBots;
      goal = false;
      myControl = control;
      myWeight = weight;
```

```
    setNextArgument(ArArg("formation position", &formationPosition,
"The formation position of this robot"));
}

/*
  Sets the myRobot pointer (all setRobot overloaded functions must do
this),
  finds the sonar device from the robot, and if the sonar isn't there,
  then it deactivates itself.
*/
void ActionAvoidObstacle::setRobot(ArRobot *robot)
{
  myRobot = robot;
  mySonar = myRobot->findRangeDevice("sonar");
  if (mySonar == NULL)
    deactivate();
}

/*
  This fire is the whole point of the action.
*/
ArActionDesired *ActionAvoidObstacle::fire(ArActionDesired
currentDesired)
{
      double range, rangeNew, speed;
      coordinate vectorSum;

      // reset the actionDesired (must be done)
      myDesired.reset();

      // if the sonar is null we can't do anything, so deactivate
    if (mySonar == NULL)
      {
      deactivate();
      return NULL;
      }

      if(goal == true)
      {
            myControl->setVelocity(0);
            myDesired.setVel(0);
            return &myDesired;
      }

      //Error Checking
      cout << "Inside O.A." << endl;
      ArUtil::sleep(1000);

      //Get the range off the sonar where not another robot
      for(int j = -70; j < 70; j+=10)
      {
            if(!isRobot(j))
            {
                  rangeNew = mySonar->currentReadingPolar(j, j+10) -
1.5 *(myRobot->getRobotRadius());
                  if(rangeNew > 0 && rangeNew < 2500 && rangeNew > -1)
                  {
```

```
                        if(rangeNew < range)
                              vectorSum =
obstacles.addObstacle(rangeNew, j+5);
                        else
                              vectorSum =
obstacles.subObstacle(rangeNew, j+5);

                        range = rangeNew;
                  }
            }
      }

      double currentSpeed = myRobot->getVel();
      double obstacleX = -vectorSum.getX();
      double obstacleY = -vectorSum.getY();
      double obstacleTh = atan2(obstacleY, obstacleX);

      double differenceTh = myRobot->getTh() - obstacleTh;
      myControl->addDeltaAngle(.5 * differenceTh, myWeight);

      // More output for monitoring / error checking purposes
      cout << endl << "Range: " << range << endl;
      cout << "DifferenceTh: " << differenceTh << endl << endl;
      ArUtil::sleep(1000);

      if(range < 1000)
            speed = currentSpeed - range;
      else
            speed = currentSpeed;

      // if that speed is greater than our max, cap it
    if (speed > myMaxSpeed)
            speed = myMaxSpeed;
      else if(speed < -myMaxSpeed)
            speed = -myMaxSpeed;

    // now set the velocity
      myControl->addVelocity(speed, myWeight);
      myDesired.setVel(myRobot->getVel());

      // return a pointer to the actionDesired, so resolver knows what
to do
      return &myDesired;
}

/*
Checks to see if the angle we are looking at is another robot
*/

bool ActionAvoidObstacle::isRobot(double angle)
{
      // Set the local coordinates for the rest of the formation
      // The positions of the other robots, adjusted to local
positioning

      coordinate myPosition =
myFormation.getPosition(formationPosition);
```

```
	double positionX = myPosition.getX();
	double positionY = myPosition.getY();

	for(int i = 0; i < numRobots; i++)
	{
		if(i != (formationPosition - 1))
		{
			// The global position of the formation
			coordinate position = myFormation.getPosition(i);
			int oldX = position.getX();
			int oldY = position.getY();
			// Adjust to local positioning by subtracting the
current bot's position
			double newX = oldX - positionX;
			double newY = oldY - positionY;
			// Put into rotaional (angle) coordinates
			double otherRobot = ArMath::atan2(newY, newX);
			if(!(((otherRobot - myRobot->getRobotRadius()) <
(angle - 5)) || ((otherRobot + myRobot->getRobotRadius()) > (angle +
5))))
			{
				return true;
				break;
			}
		}
	}

	return false;
}

// Absolute value
double ActionAvoidObstacle::abs(double value)
{
	if(value < 0)
		return -value;
	else
		return value;
}

// stop avoiding when acheived goal
void ActionAvoidObstacle::goalDone()
{
	obstacles.reset();
	goal = true;
}

// start avoiding when there is a new goal
void ActionAvoidObstacle::newGoal()
{
	goal = false;
}


/*
Definition for the BuildObstacleMap class
*/
```

```
#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "formationClass.h"

class BuildObstacleMap
{
public:
	// Constructor
	//BuildObstacleMap(formationClass newFormation);
	//Default Constructor
	BuildObstacleMap();
	// Get Sum of Obstacle Vectors
	//coordinate calculateVector(void);
	// Add obstacle to Obstalce Map, returns true if successful
	coordinate addObstacle(coordinate obstacle);
	coordinate addObstacle(double obstacle, double angle);
	coordinate subObstacle(double obstacle, double angle);
	void reset();

protected:
	// The formation for which to track obstacles
	//formationClass myFormation;
	// number of robots in the system
	//int numRobots;
	// Sum of current vectors
	coordinate vectorSum;
	// collection of obstacles (start with empty space)
	//coordinate obstacles[1];

};


/*
BuildObstacleMap.cpp
This is a supporting class that allows the system to
keep track of all of the obstacles it detects in the
local environment while attempting to avoid them.
*/

#include "BuildObstacleMap.h"


//Default Constructor
BuildObstacleMap::BuildObstacleMap()
{
	vectorSum.setX(0);
	vectorSum.setY(0);
}

// Add an obstacle to the growing collection
// returns a new sum of the obstacle coordinates
coordinate BuildObstacleMap::addObstacle(coordinate obstacle)
{
	int x = obstacle.getX();
	int y = obstacle.getY();
```

```
	int sumX = vectorSum.getX();
	int sumY = vectorSum.getY();

	int newSumX = (x + sumX);
	int newSumY = (y + sumY);

	vectorSum.setX(newSumX);
	vectorSum.setY(newSumY);

	return vectorSum;
}

coordinate BuildObstacleMap::addObstacle(double obstacle, double angle)
{
	int x = ArMath::cos(angle) * obstacle;
	int y = ArMath::sin(angle) * obstacle;

	int sumX = vectorSum.getX();
	int sumY = vectorSum.getY();

	int newSumX = (x + sumX);
	int newSumY = (y + sumY);

	vectorSum.setX(newSumX);
	vectorSum.setY(newSumY);

	return vectorSum;
}

coordinate BuildObstacleMap::subObstacle(double obstacle, double angle)
{
	int x = ArMath::cos(angle) * obstacle;
	int y = ArMath::sin(angle) * obstacle;

	int sumX = vectorSum.getX();
	int sumY = vectorSum.getY();

	int newSumX = (x - sumX);
	int newSumY = (y - sumY);

	if(newSumX < 0)
		newSumX = 0;
	if(newSumY < 0)
		newSumY = 0;

	vectorSum.setX(newSumX);
	vectorSum.setY(newSumY);

	return vectorSum;
}

void BuildObstacleMap::reset()
{
	vectorSum.setX(0);
	vectorSum.setY(0);
}
```

```
/*
Definition for formationClass
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "coordinate.h"
#include <math.h>

const MaxNumRobots = 5;

class formationClass
{
public:
      // The constructor
      formationClass(int numOfRobots, coordinate* positions);
      // A constructor overload with myPositions defaults of (0,0)
      formationClass(int numOfRobtos);
      formationClass();
      // Access function
      int getNumRobots(void);
      // Get the transform for the a position to global coordinates
      ArTransform getGTransform(int position, ArPose currentPosition);
      // Get the coordinates of the individual robots
      coordinate getPosition(int positionIndex);
      // Set the positions coordinates (change them)
      void setPosition(int positionIndex, coordinate myCoordinate);
      // calculate the ideal angle for robots at two coordinates
      double getIdealAngle(coordinate cord1, coordinate cord2);
protected:
      // The number of robots in the system
      const int myNumOfRobots;
      // The positions of the formation
      coordinate myPositions[MaxNumRobots];
};


/*
formationClass.cpp
This class keeps track of the formation information,
such as distances and angles
*/

#include "formationClass.h"

// Very basic Constructor
formationClass::formationClass(int numOfRobots, coordinate positions[])
: myNumOfRobots(numOfRobots)
{
      //myNumOfRobots = numOfRobots;
      for(int i = 0; i < myNumOfRobots; i++)
            myPositions[i] = positions[i];
}

// Very basic Constructor
```

```
formationClass::formationClass(int numOfRobots)
: myNumOfRobots(numOfRobots)
{
	//myNumOfRobots = numOfRobots;
	coordinate c = coordinate(0,0);
	for(int i = 0; i < numOfRobots; i++)
	{
		myPositions[i] = c;
	}
}

// default and empty constructor
formationClass::formationClass()
: myNumOfRobots(1)
{
	//myNumOfRobots = 1;
	coordinate c = coordinate(0,0);
	myPositions[0] = c;
}

int formationClass::getNumRobots()
{
	return myNumOfRobots;
}

// Each robot has local coordinates (thinks it is at (0,0)) so we need
// to convert every coordinate that they changed into the global
coordinates
ArTransform formationClass::getGTransform(int position, ArPose
currentPosition)
{
	ArPose original, transformed;
	ArTransform newTransform;

	int oldX = currentPosition.getX();
	int oldY = currentPosition.getY();
	coordinate c = myPositions[position-1];
	int newX = oldX + c.getX();
	int newY = oldY + c.getY();

	original.setPose(oldX, oldY);
	transformed.setPose(newX, newY);

	newTransform.setTransform(original, transformed);

	return newTransform;
}

coordinate formationClass::getPosition(int positionIndex)
{
	return myPositions[positionIndex-1];
}

void formationClass::setPosition(int positionIndex, coordinate
myCoordinate)
{
	myPositions[positionIndex-1] = myCoordinate;
```

```
}

double formationClass::getIdealAngle(coordinate cord1, coordinate
cord2)
{
      double x, y, z, angle;
      x = cord2.getX() - cord1.getX();
      y = cord2.getY() - cord1.getY();

      z = ArMath::distanceBetween(cord1.getX(), cord1.getY(),
cord2.getX(), cord2.getY());

      angle = acos(((y*y) + (z*z) - (x*x))/(2*y*z));

      return angle;
}

double getIdealAngle(coordinate cord1, coordinate cord2)
{
      double x, y, z, angle;
      x = cord2.getX() - cord1.getX();
      y = cord2.getY() - cord1.getY();

      z = ArMath::distanceBetween(cord1.getX(), cord1.getY(),
cord2.getX(), cord2.getY());

      angle = acos(((y*y) + (z*z) - (x*x))/(2*y*z));

      return angle;
}


/*
      This class is a simple way to represent the
      pairs of x and y coordinates needed to maintain
      global representation of the robots' environment
*/

class coordinate
{
public:
      // Two basic constructors
      coordinate();
      coordinate(int x, int y);
      int getX(void);
      int getY(void);
      void setX(int newX);
      void setY(int newY);
protected:
      int myX, myY;
};


/*
coordinate.cpp
This is just a short supporting class that helps to
reduce confusion by creating a coordinate as a single
```

```
object with an x and a y value
*/

#include "coordinate.h"

coordinate::coordinate()
{
      myX = 0;
      myY = 0;
}

coordinate::coordinate(int x, int y)
{
      myX = x;
      myY = y;
}

int coordinate::getX(void)
{
      return myX;
}

int coordinate::getY(void)
{
      return myY;
}

void coordinate::setX(int newX)
{
      myX = newX;
}

void coordinate::setY(int newY)
{
      myY = newY;
}
```

B.5 The Follower Robot Implementation

```
/*
SimpleFollow.cpp
This is the implementation of the following robot behavior
for maintain distances.  It contains the main() that controls
the following robot.  It also sets up the robot interface.
*/

#include "Aria.h"
#include "PADRequest.h"
#include <stdio.h>
#include <iostream.h>
#include "ActionMaintainDistance.h"
#include "PADFunctions.h"

int main(void)
{
  double goalRange;
```

```
  int inFront;
  bool frontFlag = false;
  bool simulator;

    //Set up Ultra Wide Band
      long int rate;
      PADRequest* PADComm = initializePAD();
      rate = PADComm->RequestRateGet();
    PADComm->VerbosityReadSet(0);
      PADComm->VerbosityWriteSet(0);


  //Set up Pioneer Robot
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // Make a key handler, so that escape will shut down the program
  // cleanly
  ArKeyHandler keyHandler;

  // Add the key handler to Aria so other things can find it
  Aria::setKeyHandler(&keyHandler);

  // Attach the key handler to a robot now, so that it actually gets
  // some processing time so it can work, this will also make escape
exit
  robot.attachKeyHandler(&keyHandler);

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
      simulator = true;
  }
  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
    // device

    // modify the next line if you're not using the first serial port
```

```
    // to talk to your robot
    serConn.setPort();
    printf(
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
      simulator = false;
  }


  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  // Get the user defined parameters for the system
  cout << "Current range is: " << getRange (PADComm, simulator, 0, 0,
false) << endl;
  cout << "how far away do you want to keep the robot?" << endl;
  cin >> goalRange;
  cout << "is this robot in front? Enter 1 if yes." << endl;
  cin >> inFront;

  // If the robot is in front, then to move closer to the other robot
  //  then this robot needs to move backward rather than forward
  if(inFront == 1)
        frontFlag = true;

  // the behaviors from above, and a stallRecover behavior that uses
defaults
  ArActionAvoidFront avoid;
  ArActionStallRecover recover;
  ActionMaintainDistance maintainDistance(goalRange, PADComm,
frontFlag, simulator);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
  robot.addAction(&recover, 100);
  robot.addAction(&maintainDistance, 50);
  //robot.addAction(&avoid, 45);

  // run the robot, the true here is to exit if it loses connection
  robot.run(true);

  // now just shutdown and go away
  Aria::shutdown();
  return 0;
```

```
}
```

B.6 The Action Maintain Distance Behavior and UWB Access Files

```
/*
Defintion of the ActionMaintainDistance class
*/

#include "Aria.h"
#include "PADRequest.h"
#include <stdio.h>
#include <iostream.h>


class ActionMaintainDistance : public ArAction
{
public:
  // constructor, sets myDistance, robot, and the PAD
  ActionMaintainDistance(double distance, PADRequest* PADComm, bool
inFront, bool simulator);
  // destructor, its just empty, we don't need to do anything
  virtual ~ActionMaintainDistance(void) {};
  // fire, this is what the resolver calls to figure out what this
action wants
  virtual ArActionDesired *fire(ArActionDesired currentDesired);
  // sets the robot pointer, also gets the sonar device
  virtual void setRobot(ArRobot *robot);
protected:
  // this is to hold the sonar device form the robot
  ArRangeDevice *mySonar;
  // what the action wants to do
  ArActionDesired myDesired;
  // distance to stop at
  double myDistance;
  // myFrontFlag is true if the robot is in front of the other
  bool myFrontFlag;
  // mySimulator is true if we are using the simulator
  bool mySimulator;
  // need to keep track of the current range for thhe simulator
  double myRange;
  // Array to check that error is getting smaller
  double errors[2];

  PADRequest* myPADComm;
};


/*
File:  ActionMaintainDistance.cpp
This is the action definition for the Maintain Distance Behavior
It uses the Ultra Wideband functionality to determine the distance
between two UWB units and then maintains the desired range.
*/
```

```
#include "Aria.h"
#include "PADRequest.h"
#include <stdio.h>
#include <iostream.h>
#include "PADFunctions.h"
#include "ActionMaintainDistance.h"
#include <fstream.h>

const double warningRange = 2.0;
const char BEEP = '\a';

/*
  This is the constructor
*/

ActionMaintainDistance::ActionMaintainDistance(double distance,
PADRequest* PADComm, bool inFront, bool simulator) :
  ArAction("Distance")
{
  myDistance = distance;
  myPADComm = PADComm;
  myFrontFlag = inFront;
  mySimulator = simulator;
  myRange = 0;

  setNextArgument(ArArg("distance maintained", &myDistance, "Distance
to maintain from other units."));
}

/*
  Sets the myRobot pointer (all setRobot overloaded functions must do
this),
  finds the sonar device from the robot, and if the sonar isn't there,
  then it deactivates itself.
*/
void ActionMaintainDistance::setRobot(ArRobot *robot)
{
  myRobot = robot;
  mySonar = myRobot->findRangeDevice("sonar");
  if (mySonar == NULL)
    deactivate();
}

/*
  This fire is the whole point of the action.
*/
ArActionDesired *ActionMaintainDistance::fire(ArActionDesired
currentDesired)
{
      double rangeError, velocity;

    // For Logging purposes
      ofstream file;
      file.open("d:\\testData.txt", ios::app);

      // reset the actionDesired (must be done)
      myDesired.reset();
```

```
      myRange = getRange(myPADComm, mySimulator, myRange, myRobot-
>getVel(), myFrontFlag);

    while (myRange == 0)
      {
            myRange = getRange (myPADComm, mySimulator, myRange,
myRobot->getVel(), myFrontFlag);
      }
    rangeError = myRange - myDistance;

    cout << "RANGE = " << myRange << " : range error = " << rangeError
<< endl;
      file << "RANGE = " << myRange << " : range error = " <<
rangeError << "\n";
      file.close();

      velocity = computeVelocity (rangeError);

    if(myRange < myDistance)
            velocity = -velocity;

      if(myFrontFlag)
            velocity = -velocity;

      // now set the velocity
    myDesired.setVel(velocity);

      // return a pointer to the actionDesired, so resolver knows what
to do
      return &myDesired;
}

/*
The definitions for the PADFunctions file
*/

#include "Aria.h"
#include "PADRequest.h"
#include <stdio.h>
#include <iostream.h>

double getRange(PADRequest* PADComm, bool simulator, double range,
double velocity, bool inFront );
PADRequest* initializePAD ();

double mmToFeet (double mm);
double feetToMM (double feet);
double computeVelocity (double error);
double abs (double number);


/*
PADFunctions.cpp
Program for getting the UWB range information
Origianlly created by Zac Randles, now modified
*/
```

```
const int ACTIVE_PAD = 0;
const double rangeTolerance = .1;
const double maxVelocity = 500;
const double maxSleep = 1000;

#include "PADFunctions.h"

PADRequest* initializePAD ()
{
  int serialNumPADs[10];
  char *namesPADs[2];
  int k, numpads;

  serialNumPADs[0] = 387;
  serialNumPADs[1] = 388;

  //static IPs - For use with crossover cable configuration
  namesPADs[0] = "10.1.4.131";
  namesPADs[1] = "10.1.4.132";
  numpads = 2;

  // make a new PADComm object for each PAD I want to talk to
  // index of PAD i'm going to communicate with
  k = ACTIVE_PAD;
  PADRequest *PADComm = new PADRequest (namesPADs[k], 9250,
serialNumPADs[k]);

  // Initialize this PAD with the serial numbers of the other PADs its
going
  // to talk to
  PADComm->PADRequestInit( numpads, serialNumPADs );

  //Initialize a request for TOF measurements. Put in optional payload
  char *payload = "payload for 387";
  PADComm->PADTOFRequest( payload );

  //Initialize a command request with a payload
  PADComm->PADCommandRequest( 8, payload );

  // Set up frequency of repeated requests in milliseconds
  PADComm->RequestRateSet( (long int) ( 1000) );

  //return the newly created and configured PADRequest pointer
  return PADComm;
}


double mmToFeet (double mm) { return mm * .00328084; }
double feetToMM (double feet) { return feet / .00328084; }

double getRange(PADRequest* PADComm, bool simulator, double range,
double velocity, bool frontFlag )
{

  if(simulator)
  {
```

```
    ArUtil::sleep(1000);

    // get a random number
    double difference = abs(ArMath::random() % 1000);

    // if range is zero, this is the first reading so just return
    // a random number
    if(range == 0)
          return difference;

    // if the difference is greater than the range, find a smaller
    // number to use as the difference
    while(difference > range)
          difference = difference - range;

    // output the number, just to see the range we are getting
    cout << "difference:   " << difference << endl;

    if(velocity == 0)
          return range;

    if(!frontFlag)
    {
          // if we are moving backward, then we want are moving away
          // from the robot, distance should be increasing so we add
          if(velocity < 0)
                return range + abs(difference);

          // if we are moving forward, then we are moving toward the
          //  other bot, distance should be decreasing so we subtract
          else
                return range - abs(difference);
    }

    else
    {
          //the exact opposite of the above
          if(velocity > 0)
                return range + abs(difference);

          else
                return range - abs(difference);
    }

} // end simulator portion

// not using the simulator, get actual PAD data
else
{
      double newRange;
      unsigned long int tof;
      char outputPayload[ PAYLOAD_MAX_SIZE ];
      PADComm->TOFRequestSend();
      PADComm->ResponseRead( &outputPayload[0], &tof );
      return (double) tof * 0.000494;
```

```
  }
} // end getRange function



double computeVelocity (double error)
{
  double velocity = abs (feetToMM (error) );

  if (velocity > maxVelocity) { velocity = maxVelocity; }
  return velocity;

}

double abs (double number)
{
  if (number < 0) { number = -number; }
  return number;
}


/*
PADRequest definitions
*/

#ifndef padrequest_h
#define padrequest_h


#define MAXHOSTNAME 15
#define PAYLOAD_MAX_SIZE  1000
#define MAX_NUM_PADS  3
#define MAX_NAME_LEN 15
#define PACKET_LEN 72
#define RANGE_REQUEST_TYPE 1
#define RANGE_REQUEST_PLD 8
#define DEFAULT_PORT 9935
const int SEND_PICTURE = 2;
const int NO_OUTPUT = 0;

typedef struct PADPacketType
{
  unsigned short int Type;
  unsigned short int Target;
  unsigned short int Source;
  unsigned short int Channel;
  unsigned short int Retry;
  unsigned short int Ack;
  unsigned long int CorrectedTOF;
  signed short int EstimatedAOA;
  signed short int AcqHeaderSizeInMS;
  unsigned long int PacketNumber;
  unsigned short int ResponderHeaderSizeInMS;
  unsigned short int RequesterHeaderSizeInMS;
  unsigned long int FencePeakValue;
  unsigned short int temp1;
  unsigned short int temp2;
```

```
  unsigned short int temp3;
  unsigned short int temp4;
  unsigned long int tempL1;
  unsigned long int tempL2;
  unsigned long int tempL3;
  unsigned short int PayloadSize;
  unsigned char payload[PAYLOAD_MAX_SIZE];
} *PADPacketTag;

//Public
class PADRequest
{
 protected:
  long int          _RequestRate;  /* reference */
  double              _Request;  /* output */

 public:
  PADRequest( char *PADName, unsigned short PADPort, int PADSerialNum
);
  ~PADRequest();

  int PADCommandRequest( unsigned short command, char *inputPayload );
  int PADTOFRequest( char *payload );
  int TOFRequestSend();
  int RequestRateSet( int rate /* in microseconds*/ );
  int RequestRateGet();
  int PayloadSet( char *payload, int size, int target, PADPacketType
packets[]);

  int ResponseRead( char *outputPayload, unsigned long *TOF);
  int Request();
  int PADRequestInit( int numPADs, int *PADSerialNumbers );

  int SourceSet();
  int PacketDump( int verbosity, char * packet );
  int VerbosityReadSet( int verbosity );
  int VerbosityWriteSet( int verbosity );

 private:
  PADPacketType _RequestPackets[ MAX_NUM_PADS ];
  PADPacketType _TOFPackets[ MAX_NUM_PADS ];
  PADPacketType _ResponsePacket;


  int CommunicationsInit();
  int RequestPacketSet( int type, int ack, int target, PADPacketType
packetArray[]);
  int RequestSend( int type );
  /* Info on all PADs this PAD will talk to */
  int _PADSerialNumbers[ MAX_NUM_PADS ];
  int _numPADs;

  /* Info on PAD associated with this object */
  char  _PADHostName[MAX_NAME_LEN];
  sockaddr_in _saServer;
  unsigned short _PADPORT;
  int _PADSerialNum;
```

```
  int _PADIndex;

  /* Data to be sent between PADs */
  char *_sendingBuffers[ MAX_NUM_PADS ];
  char *_TOFSendingBuffers[ MAX_NUM_PADS ];
  unsigned short _requestType;

  /* Info for PC program trying to talk to remote PAD */
  char _responseBuffer[ PACKET_LEN*2 ];
  int _requestChanged;
  int _TOFCopyBuffer;
  WSADATA _wsaData;
  SOCKET _clientSocket;


  /* debugging variables */
  int _sendingVerbosity;
  int _receivingVerbosity;

  /* Private Methods */
  int ClientSocket( char *remoteHostname, unsigned short remotePort);
  int SocketRead( int socket, char *buffer, int numBytes );
};

#endif



/* PADRequest.cxx \-  description

modification history
--------------------
tnc, 17apr2002, Skeleton generated
tnc, 23may2002, Transition from control shell code to plain C++ code.

  DESCRIPTION:

   This file implements the class for the PADRequest object.

   Socket implementations should probably also be separated out into
   another file.


=============================================================================
=== */

#include <stdio.h>
#include <winsock.h>
#include "PADRequest.h"

#include <iostream.h>


/*************************************************************************
**********/

/* ================   PADRequest Class ======================*/
```

```
PADRequest::PADRequest( char *PADName, unsigned short PADPort, int
PADSerialNumber )
{
  _RequestRate = 10; /* default rate of 10 Hz */
  _numPADs = 0;
  _PADSerialNumbers[0] = 0;
  _PADSerialNumbers[1] = 0;
  _PADIndex = 0;

  _PADPORT = PADPort;
  _PADSerialNum = PADSerialNumber;
  strcpy( _PADHostName, PADName );

  _receivingVerbosity = 0;
  _sendingVerbosity = 1;

  _requestChanged = 1;
}


PADRequest::~PADRequest()
{
  int i;
  for( i = 0; i < _numPADs; i++ )
  {
      if( _sendingBuffers[i] ) { delete _sendingBuffers[i]; }
      if( _TOFSendingBuffers[i] ) { delete _TOFSendingBuffers[i]; }
  }

  closesocket(_clientSocket);
  WSACleanup();
}


int PADRequest::RequestPacketSet( int type, int ack, int target,
PADPacketType packetArray[])
{
  /* first get the correct request packet */
  int i, packetIndex;
  PADPacketTag RequestPacket;

  /* find index of target */
  packetIndex = -1;
  for( i = 0; i < _numPADs; i++ )
  {
        if( _PADSerialNumbers[i] == target ) { packetIndex = i; }
  }

  if( packetIndex >= 0 ) { RequestPacket = &packetArray[ packetIndex ];
}
  else
  {
    printf("Can't find target %d\n", target );
    return(-1);
  }
```

```
  memset(RequestPacket, 0, sizeof(*RequestPacket));
  RequestPacket->Source = _PADSerialNum;  /* set source to me */

  RequestPacket->Type = type;
  printf("Setting Type to %d\n", type);
  RequestPacket->Ack = ack;
  RequestPacket->Target = target;

  // If Error, return negative value
  return 0;
}

int PADRequest::RequestRateSet( int rate )
{
  _RequestRate = rate;
  return 0;
}


int PADRequest::RequestRateGet() { return (_RequestRate); }

int PADRequest::PADCommandRequest( unsigned short command, char
*inputPayload )
{
      int i;

      _requestType = (unsigned short) command;

      /* Set up the request packets */
      for( i = 0; i < _numPADs; i++ )
      {
            if( i != _PADIndex )
            {
                  RequestPacketSet( _requestType, 1,
_PADSerialNumbers[i],_RequestPackets );
                  PayloadSet( inputPayload, strlen( inputPayload
),_PADSerialNumbers[i], _RequestPackets);
            }
  }
      _requestChanged = 1;
      return(1);
}

int PADRequest::PADTOFRequest( char *payload )
{
      int i;
      if( !payload )
      {
        for( i = 0; i < _numPADs; i++ )
        {
            if( i != _PADIndex )
            {
            RequestPacketSet( RANGE_REQUEST_TYPE, 1,
_PADSerialNumbers[i],_TOFPackets );
            _TOFCopyBuffer = 1;
            }
        }
```

```
      }
      else
      {
            for( i = 0; i < _numPADs; i++ )
            {
                  if( i != _PADIndex )
                  {
                        RequestPacketSet( RANGE_REQUEST_PLD, 1,
_PADSerialNumbers[i],_TOFPackets );
                        PayloadSet(payload, strlen(payload),
_PADSerialNumbers[i], _TOFPackets);
                        _TOFCopyBuffer = 1;
                  }
            }
      }
      return(1);
}

int PADRequest::TOFRequestSend()
{
      RequestSend( RANGE_REQUEST_TYPE );
      return(1);
}


int PADRequest::PADRequestInit( int numPADs, int *PADSerialNumbers )
{
  int i;
  int *ptr = PADSerialNumbers;

  _numPADs = numPADs;
  if( _numPADs  > MAX_NUM_PADS )
  {
    _numPADs = MAX_NUM_PADS;
  }
  for( i = 0; i < _numPADs; i++ )
  {
    _PADSerialNumbers[i] = *ptr;
    ptr++;
    _sendingBuffers[i] = new char[(sizeof(_RequestPackets[i]))];
      _TOFSendingBuffers[i] = new char[(sizeof(_TOFPackets[i]))];
      memset(_sendingBuffers[i], 0, sizeof(_sendingBuffers[i]));
      memset(&_RequestPackets[i], 0, sizeof(_RequestPackets[i]));
      memset(&_TOFPackets[i], 0, sizeof(_TOFPackets[i]));
      memset(_TOFSendingBuffers[i], 0, sizeof(_TOFSendingBuffers[i]));
      if(!ptr) return(-1);
  }

  /* find index of self */
  for( i = 0; i < _numPADs; i++ )
  {
    if( _PADSerialNumbers[i] == _PADSerialNum )
      {
      _PADIndex = i;
      printf("My index is %d\n", _PADIndex);
    }
  }
```

```
  if( int retval = WSAStartup( 0x202, &_wsaData) != 0)
  {
        fprintf( stderr, "WSAStartup failed with error %d\n", retval );
        WSACleanup();
        return(-1);
  }

  CommunicationsInit();
  return(1);
}

int PADRequest::PayloadSet( char *payload, int length, int target,
PADPacketType packets[])
{
  /* find appropriate request packet */
 /* first get the correct request packet */
  int i, packetIndex;
  PADPacketTag RequestPacket;

  packetIndex = -1;
  for( i = 0; i < _numPADs; i++ )
  {
    if( _PADSerialNumbers[i] == target )
        {
      packetIndex = i;
          break;
    }
  }
  if( packetIndex >= 0 ) { RequestPacket = &packets[packetIndex]; }
  else
  {
    printf("Can't find target %d\n", target );
    return(-1);
  }
  RequestPacket->PayloadSize = length;
  memcpy( RequestPacket->payload, payload, length);
  return(1);
}

int PADRequest::CommunicationsInit()
{
  if(_numPADs == 0)
  {
    printf("Must have at least one PAD\n");
    return(-1);
  }
  /* open a socket to the PAD on the local PC */
  if( !_PADHostName )
  {
    printf("Must declare DNS name of PAD before creating socket\n");
    return(-1);
  }
  ClientSocket( _PADHostName, _PADPORT);

  return(1);
}
```

```
int PADRequest::RequestSend( int type )
{
  int i;
  static int counter = 0;
  int retval;

  /* for now, we have to loop through all PADS we want our PAD to talk
   * to , since its a point to point communication structure */

  if ( type == RANGE_REQUEST_TYPE || type == RANGE_REQUEST_PLD )
  {
        for( i = 0; i <  _numPADs; i++ )
        {
            /* don't send request to self */
            if(   _PADSerialNumbers[i] != _PADSerialNum )
            {
                  /* here we copy our request packet into a sending
byte buffer
                  * temporary: whenever anything changes, all packets
recopied */
                  if( _TOFCopyBuffer )
                  {
                        memcpy
                        (
                              (void *)_TOFSendingBuffers[i],
                              (void *)(& _TOFPackets[i]),
                              sizeof( _TOFPackets[i] )
                        );
                        PacketDump( _sendingVerbosity,
_TOFSendingBuffers[i]);
                  }

                  retval = sendto
                             (
                                    _clientSocket,
_TOFSendingBuffers[i],
                                    sizeof(_TOFPackets[i] ), 0,
                                    (struct sockaddr *) &( _saServer ),
                                    sizeof( _saServer)
                              );

                  if(retval == SOCKET_ERROR)
                  {
                        fprintf(stderr, "send() failed: error %d\n",
WSAGetLastError());
                        WSACleanup();
                        return(-1);
                  }

                  PacketDump( _sendingVerbosity, _TOFSendingBuffers[i]
);
                  counter++;
            }
        }

        _TOFCopyBuffer = 0;
```

```
  }
  else
  {
            printf ("TOBE: type Command not implemented in SEND \n");

            for( i = 0; i <  _numPADs; i++ )
            {
                  if(   _PADSerialNumbers[i] != _PADSerialNum )
                  {
                        /* use the _requestChanged flag here */

                        memcpy
                      (
                              (void *)_sendingBuffers[i],
                              (void *)(& _RequestPackets[i]),
                              sizeof( _RequestPackets[i] )
                      );

                        sendto
                        (
                              _clientSocket, _sendingBuffers[i],
                              sizeof(_RequestPackets[i] ), 0,
                              (struct sockaddr *) &( _saServer ),
                              sizeof( _saServer)
                        );
                  }
            }
  }

  return(1);
}

int PADRequest::ResponseRead( char *outputPayload, unsigned long *TOF)
{
 /* don't know what i want to do here yet.. This only works for one
       * response, and its blocking! */

       /* clean out response buffer */
  memset( _responseBuffer, 0,PACKET_LEN );
  int n = recv( _clientSocket, &_responseBuffer[0], PACKET_LEN, 0 );
  if( n == SOCKET_ERROR)
  {
        fprintf( stderr, "recv() failed: error %d\n",
WSAGetLastError());
        return(-1);
  }

  /* now convert these bytes back to a packet.*/
  memcpy( (void *)(&_ResponsePacket), (void *)_responseBuffer,sizeof(
_ResponsePacket));
  PacketDump(_receivingVerbosity, (char *)&_ResponsePacket );

  printf("\n");

  /* copy data to output */
  if( TOF )
  {
```

```
      *TOF =  _ResponsePacket.CorrectedTOF;
  }
  if(outputPayload) { memcpy( outputPayload, _ResponsePacket.payload,
PAYLOAD_MAX_SIZE); }
  return(1);
}


int PADRequest::ClientSocket( char *remoteHostAddress, unsigned short
remotePort )
{
      struct sockaddr_in saClient;
      //struct hostent *lpHostEntry;
      unsigned long IPAddress;

  /* get server IP address (no check if input is IP address or DNS name
*/

  if (( IPAddress = inet_addr( remoteHostAddress )) == INADDR_NONE )
  {
    printf("not a valid IP address string \n");
    return(-1);
  }

  //need this to replace the data that use to be returned by
gethostbyaddr
  unsigned long fakeAddressArray [1];
  fakeAddressArray[0] = IPAddress;

  printf
  (
      "sending data to '%s' (IP : %s) \n",  _PADHostName,
      inet_ntoa(*(struct in_addr *)fakeAddressArray)
  );

  // set information about the server we want to talk to
  memset( &_saServer, 0, sizeof(_saServer));
  memcpy( (char *)&_saServer.sin_addr.S_un.S_addr, fakeAddressArray,
sizeof(IPAddress));
  _saServer.sin_family = AF_INET;
  _saServer.sin_port = htons( remotePort );

  // socket creation
  _clientSocket = socket( AF_INET, SOCK_DGRAM, 0);
  if( _clientSocket < 0)
  {
    printf(" Cannot open socket.  Error %d\n", WSAGetLastError() );
      WSACleanup();
    return(-1);
  }


  // bind any local port
  // set up local client properties
      saClient.sin_family = AF_INET;
      saClient.sin_addr.S_un.S_addr = htonl(INADDR_ANY);
      saClient.sin_port = htons(0);
```

```
  if ( bind(_clientSocket,(struct sockaddr*) &saClient,
sizeof(saClient)) == SOCKET_ERROR )
  {
      fprintf(stderr, "bind() failed: %d\n", WSAGetLastError());
      WSACleanup();
      return(-1);
  }

  return( 1 );
}


int PADRequest::SocketRead( int socket, char *buffer, int numBytes )
{
  int byteread;
  byteread = 0;

  memset( buffer, 0, PACKET_LEN);
  byteread = recv( socket, buffer, numBytes, 0 );

  return(byteread);
}


int PADRequest::PacketDump( int verbosity, char *packet )
{
      PADPacketTag udpPacket;

      udpPacket = (PADPacketTag ) packet;

      if( verbosity > 0 )
      {
            printf(" Type:     %d\n", udpPacket->Type );
            printf(" Target: %d\n", udpPacket->Target );
            printf(" Source: %d\n", udpPacket->Source );
            printf(" Channel: %d\n", udpPacket->Channel );
            printf(" Retry: %d\n", udpPacket->Retry );
            printf(" Ack: %d\n", udpPacket->Ack );
            printf(" CorrectedTOF: %d\n", udpPacket->CorrectedTOF);
            printf(" EstimatedAOA: %d\n", udpPacket->EstimatedAOA );
            printf(" AcqHeaderSizeInMS: %d\n", udpPacket-
>AcqHeaderSizeInMS );
            printf(" PacketNumber: %d\n", udpPacket->PacketNumber );
            printf(" ResponderHeaderSizeInMS: %d\n", udpPacket-
>ResponderHeaderSizeInMS );
            printf(" PayloadSize: %d\n", udpPacket->PayloadSize );
            printf(" Payload: ", udpPacket->payload[0] );
            for(int i = 0; i < udpPacket->PayloadSize; i++ )
            {
                  printf(" %c ", udpPacket->payload[i] );
            }
            printf("\n");

      }
      return(1);
}
```

```
int PADRequest::VerbosityReadSet( int verbosity )
{
      _receivingVerbosity = verbosity;
      return(1);
}

int PADRequest::VerbosityWriteSet( int verbosity )
{
      _sendingVerbosity  = verbosity;
      return(1);
}
```

B.7 The Maintain Angle Behavior Including Angle of Arrival and Compass Files

```
/*
SimpleAngle.cpp
This is an example of how to get the angle from the Ultra Wideband
if the current system setup allowed for that functionality.
Note that PADFunctions needs to be changed a bit as well
*/

#include "PADFunctions.h"

int main()
{

            //Set up Ultra Wide Band
            long int rate;
            PADRequest* PADComm = initializePAD();
            rate = PADComm->RequestRateGet();
            PADComm->VerbosityReadSet(0);
            PADComm->VerbosityWriteSet(0);

      while(true)
      {

        unsigned long int tof;
        signed short int aoa = 99;
        char outputPayload[ PAYLOAD_MAX_SIZE ];
        PADComm->TOFRequestSend();
        PADComm->ResponseRead( &outputPayload[0], &tof, &aoa );

            cout << "tof: " << tof << endl;
            cout << "Angle of Arrival: " << aoa << endl;
            cout << "Angle / 3600: " << aoa / 3600 << endl;
      }

      return 0;
}


class PADRequest;
/* PADRequest \-  description
```

```
modification history
--------------------
tnc, 17apr2002, Skeleton generated
tnc, 23may2002, Transition from control shell code to plain C++ code.

  DESCRIPTION:

   This file implements the class for the PADRequest object.

   Socket implementations should probably also be separated out into
   another file.


=============================================================================
=== */

#include <stdio.h>
#include <winsock.h>
#include "PADRequest.h"

#include <iostream.h>

/*************************************************************************
**********/

/* Added get Angle of Arrival to ResponseRead 3/8/03 */


/* ================   PADRequest Class ======================*/

PADRequest::PADRequest( char *PADName, unsigned short PADPort, int
PADSerialNumber )
{
  _RequestRate = 10; /* default rate of 10 Hz */
  _numPADs = 0;
  _PADSerialNumbers[0] = 0;
  _PADSerialNumbers[1] = 0;
  _PADIndex = 0;

  _PADPORT = PADPort;
  _PADSerialNum = PADSerialNumber;
  strcpy( _PADHostName, PADName );

  _receivingVerbosity = 1;
  _sendingVerbosity = 1;

  _requestChanged = 1;
}


PADRequest::~PADRequest()
{
  int i;
  for( i = 0; i < _numPADs; i++ )
  {
      if( _sendingBuffers[i] ) { delete _sendingBuffers[i]; }
      if( _TOFSendingBuffers[i] ) { delete _TOFSendingBuffers[i]; }
```

```
  }

  closesocket(_clientSocket);
  WSACleanup();
}


int PADRequest::RequestPacketSet( int type, int ack, int target,
PADPacketType packetArray[])
{
  /* first get the correct request packet */
  int i, packetIndex;
  PADPacketTag RequestPacket;

  /* find index of target */
  packetIndex = -1;
  for( i = 0; i < _numPADs; i++ )
  {
        if( _PADSerialNumbers[i] == target ) { packetIndex = i; }
  }

  if( packetIndex >= 0 ) { RequestPacket = &packetArray[ packetIndex ];
}
  else
  {
    printf("Can't find target %d\n", target );
    return(-1);
  }

  memset(RequestPacket, 0, sizeof(*RequestPacket));
  RequestPacket->Source = _PADSerialNum;  /* set source to me */

  RequestPacket->Type = type;
  printf("Setting Type to %d\n", type);
  RequestPacket->Ack = ack;
  RequestPacket->Target = target;

  // If Error, return negative value
  return 0;
}

int PADRequest::RequestRateSet( int rate )
{
  _RequestRate = rate;
  return 0;
}


int PADRequest::RequestRateGet() { return (_RequestRate); }

int PADRequest::PADCommandRequest( unsigned short command, char
*inputPayload )
{
      int i;

      _requestType = (unsigned short) command;
```

```
      /* Set up the request packets */
      for( i = 0; i < _numPADs; i++ )
      {
            if( i != _PADIndex )
            {
                  RequestPacketSet( _requestType, 1,
_PADSerialNumbers[i],_RequestPackets );
                  PayloadSet( inputPayload, strlen( inputPayload
),_PADSerialNumbers[i], _RequestPackets);
            }
  }
      _requestChanged = 1;
      return(1);
}

int PADRequest::PADTOFRequest( char *payload )
{
      int i;
      if( !payload )
      {
        for( i = 0; i < _numPADs; i++ )
        {
            if( i != _PADIndex )
            {
            RequestPacketSet( RANGE_REQUEST_TYPE, 1,
_PADSerialNumbers[i],_TOFPackets );
            _TOFCopyBuffer = 1;
            }
        }
      }
      else
      {
            for( i = 0; i < _numPADs; i++ )
            {
                  if( i != _PADIndex )
                  {
                        RequestPacketSet( RANGE_REQUEST_PLD, 1,
_PADSerialNumbers[i],_TOFPackets );
                        PayloadSet(payload, strlen(payload),
_PADSerialNumbers[i], _TOFPackets);
                        _TOFCopyBuffer = 1;
                  }
            }
      }
      return(1);
}

int PADRequest::TOFRequestSend()
{
      RequestSend( RANGE_REQUEST_TYPE );
      return(1);
}


int PADRequest::PADRequestInit( int numPADs, int *PADSerialNumbers )
{
  int i;
```

```
  int *ptr = PADSerialNumbers;

  _numPADs = numPADs;
  if( _numPADs  > MAX_NUM_PADS )
  {
    _numPADs = MAX_NUM_PADS;
  }
  for( i = 0; i < _numPADs; i++ )
  {
    _PADSerialNumbers[i] = *ptr;
    ptr++;
    _sendingBuffers[i] = new char[(sizeof(_RequestPackets[i]))];
      _TOFSendingBuffers[i] = new char[(sizeof(_TOFPackets[i]))];
      memset(_sendingBuffers[i], 0, sizeof(_sendingBuffers[i]));
      memset(&_RequestPackets[i], 0, sizeof(_RequestPackets[i]));
      memset(&_TOFPackets[i], 0, sizeof(_TOFPackets[i]));
      memset(_TOFSendingBuffers[i], 0, sizeof(_TOFSendingBuffers[i]));
      if(!ptr) return(-1);
  }

  /* find index of self */
  for( i = 0; i < _numPADs; i++ )
  {
    if( _PADSerialNumbers[i] == _PADSerialNum )
      {
      _PADIndex = i;
      printf("My index is %d\n", _PADIndex);
    }
  }

  if( int retval = WSAStartup( 0x202, &_wsaData) != 0)
  {
        fprintf( stderr, "WSAStartup failed with error %d\n", retval );
        WSACleanup();
        return(-1);
  }

  CommunicationsInit();
  return(1);
}

int PADRequest::PayloadSet( char *payload, int length, int target,
PADPacketType packets[])
{
  /* find appropriate request packet */
 /* first get the correct request packet */
  int i, packetIndex;
  PADPacketTag RequestPacket;

  packetIndex = -1;
  for( i = 0; i < _numPADs; i++ )
  {
    if( _PADSerialNumbers[i] == target )
        {
      packetIndex = i;
          break;
    }
```

```
  }
  if( packetIndex >= 0 ) { RequestPacket = &packets[packetIndex]; }
  else
  {
    printf("Can't find target %d\n", target );
    return(-1);
  }
  RequestPacket->PayloadSize = length;
  memcpy( RequestPacket->payload, payload, length);
  return(1);
}

int PADRequest::CommunicationsInit()
{
  if(_numPADs == 0)
  {
    printf("Must have at least one PAD\n");
    return(-1);
  }
  /* open a socket to the PAD on the local PC */
  if( !_PADHostName )
  {
    printf("Must declare DNS name of PAD before creating socket\n");
    return(-1);
  }
  ClientSocket( _PADHostName, _PADPORT);

  return(1);
}

int PADRequest::RequestSend( int type )
{
  int i;
  static int counter = 0;
  int retval;

  /* for now, we have to loop through all PADS we want our PAD to talk
   * to , since its a point to point communication structure */

  if ( type == RANGE_REQUEST_TYPE || type == RANGE_REQUEST_PLD )
  {
        for( i = 0; i <  _numPADs; i++ )
        {
            /* don't send request to self */
            if(   _PADSerialNumbers[i] != _PADSerialNum )
            {
                  /* here we copy our request packet into a sending
byte buffer
                  * temporary: whenever anything changes, all packets
recopied */
                  if( _TOFCopyBuffer )
                  {
                        memcpy
                        (
                              (void *)_TOFSendingBuffers[i],
                              (void *)(& _TOFPackets[i]),
                              sizeof( _TOFPackets[i] )
```

```
                        );
                        PacketDump( 1/*_sendingVerbosity*/,
_TOFSendingBuffers[i]);
                  }

                  retval = sendto
                              (
                                    _clientSocket,
_TOFSendingBuffers[i],
                                    sizeof(_TOFPackets[i] ), 0,
                                    (struct sockaddr *) &( _saServer ),
                                    sizeof( _saServer)
                               );

                  if(retval == SOCKET_ERROR)
                  {
                        fprintf(stderr, "send() failed: error %d\n",
WSAGetLastError());
                        WSACleanup();
                        return(-1);
                  }

                  PacketDump( _sendingVerbosity, _TOFSendingBuffers[i]
);
                  counter++;
            }
         }

         _TOFCopyBuffer = 0;
   }
   else
   {
            printf ("TOBE: type Command not implemented in SEND \n");

            for( i = 0; i <  _numPADs; i++ )
            {
                  if(   _PADSerialNumbers[i] != _PADSerialNum )
                  {
                        /* use the _requestChanged flag here */

                        memcpy
                           (
                                 (void *)_sendingBuffers[i],
                                 (void *)(& _RequestPackets[i]),
                                 sizeof( _RequestPackets[i] )
                           );

                        sendto
                        (
                              _clientSocket, _sendingBuffers[i],
                              sizeof(_RequestPackets[i] ), 0,
                              (struct sockaddr *) &( _saServer ),
                              sizeof( _saServer)
                        );
                  }
            }
   }
```

```
  return(1);
}

int PADRequest::ResponseRead( char *outputPayload, unsigned long *TOF,
signed short int *aoa)
{
 /* don't know what i want to do here yet.. This only works for one
      * response, and its blocking! */

      /* clean out response buffer */
  memset( _responseBuffer, 0,PACKET_LEN );
  int n = recv( _clientSocket, &_responseBuffer[0], PACKET_LEN, 0 );
  if( n == SOCKET_ERROR)
  {
        fprintf( stderr, "recv() failed: error %d\n",
WSAGetLastError());
        return(-1);
  }

  /* now convert these bytes back to a packet.*/
  memcpy( (void *)(&_ResponsePacket), (void *)_responseBuffer,sizeof(
_ResponsePacket));
  PacketDump(_receivingVerbosity, (char *)&_ResponsePacket );

  printf("\n");

  /* copy data to output */
  //if(aoa)
  //{
        *aoa = _ResponsePacket.EstimatedAOA;
  //}

  if( TOF )
  {
      *TOF =  _ResponsePacket.CorrectedTOF;
  }


  if(outputPayload) { memcpy( outputPayload, _ResponsePacket.payload,
PAYLOAD_MAX_SIZE); }
  return(1);
}


int PADRequest::ClientSocket( char *remoteHostAddress, unsigned short
remotePort )
{
      struct sockaddr_in saClient;
      //struct hostent *lpHostEntry;
      unsigned long IPAddress;

  /* get server IP address (no check if input is IP address or DNS name
*/

  if (( IPAddress = inet_addr( remoteHostAddress )) == INADDR_NONE )
  {
```

```
    printf("not a valid IP address string \n");
    return(-1);
  }

  //need this to replace the data that use to be returned by
gethostbyaddr
  unsigned long fakeAddressArray [1];
  fakeAddressArray[0] = IPAddress;

  printf
  (
      "sending data to '%s' (IP : %s) \n",  _PADHostName,
      inet_ntoa(*(struct in_addr *)fakeAddressArray)
  );

  // set information about the server we want to talk to
  memset( &_saServer, 0, sizeof(_saServer));
  memcpy( (char *)&_saServer.sin_addr.S_un.S_addr, fakeAddressArray,
sizeof(IPAddress));
  _saServer.sin_family = AF_INET;
  _saServer.sin_port = htons( remotePort );

  // socket creation
  _clientSocket = socket( AF_INET, SOCK_DGRAM, 0);
  if( _clientSocket < 0)
  {
    printf(" Cannot open socket.  Error %d\n", WSAGetLastError() );
      WSACleanup();
    return(-1);
  }


  // bind any local port
  // set up local client properties
      saClient.sin_family = AF_INET;
      saClient.sin_addr.S_un.S_addr = htonl(INADDR_ANY);
      saClient.sin_port = htons(0);

  if ( bind(_clientSocket,(struct sockaddr*) &saClient,
sizeof(saClient)) == SOCKET_ERROR )
  {
      fprintf(stderr, "bind() failed: %d\n", WSAGetLastError());
      WSACleanup();
      return(-1);
  }

  return( 1 );
}


int PADRequest::SocketRead( int socket, char *buffer, int numBytes )
{
  int byteread;
  byteread = 0;

  memset( buffer, 0, PACKET_LEN);
  byteread = recv( socket, buffer, numBytes, 0 );
```

```
  return(byteread);
}


int PADRequest::PacketDump( int verbosity, char *packet )
{
      PADPacketTag udpPacket;

      udpPacket = (PADPacketTag ) packet;

      if( verbosity > 0 )
      {
            printf(" \n\n ");
            printf(" Type:     %d\n", udpPacket->Type );
            printf(" Target: %d\n", udpPacket->Target );
            printf(" Source: %d\n", udpPacket->Source );
            printf(" Channel: %d\n", udpPacket->Channel );
            printf(" Retry: %d\n", udpPacket->Retry );
            printf(" Ack: %d\n", udpPacket->Ack );
            printf(" CorrectedTOF: %d\n", udpPacket->CorrectedTOF);
            printf(" EstimatedAOA: %d\n", udpPacket->EstimatedAOA );
            printf(" AcqHeaderSizeInMS: %d\n", udpPacket-
>AcqHeaderSizeInMS );
            printf(" PacketNumber: %d\n", udpPacket->PacketNumber );
            printf(" ResponderHeaderSizeInMS: %d\n", udpPacket-
>ResponderHeaderSizeInMS );
            printf(" PayloadSize: %d\n", udpPacket->PayloadSize );
            printf(" Payload: ", udpPacket->payload[0] );
            for(int i = 0; i < udpPacket->PayloadSize; i++ )
            {
                  printf(" %c ", udpPacket->payload[i] );
            }
            printf("\n");
      }
      return(1);
}


int PADRequest::VerbosityReadSet( int verbosity )
{
      _receivingVerbosity = verbosity;
      return(1);
}

int PADRequest::VerbosityWriteSet( int verbosity )
{
      _sendingVerbosity  = verbosity;
      return(1);
}


/*
CompassAngle.cpp
CompassAngle is the actual current implementation for the compass and
action maintain compass files.  It contains the main().  It is
currently
```

```
not integrated with the rest of the system due to i/o irregularities.
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "ActionMaintainCompassAngle.h"

int main(void)
{
  double angle;
  bool simulator;

  completeVector control;

  //Set up Pioneer Robot
  // the serial connection (robot)
  ArSerialConnection serConn;
  // tcp connection (sim)
  ArTcpConnection tcpConn;

  // robot
  ArRobot robot;
  // sonar, must be added to the robot
  ArSonarDevice sonar;

  // mandatory init
  Aria::init();

  // Make a key handler, so that escape will shut down the program
  // cleanly
  ArKeyHandler keyHandler;

  // Add the key handler to Aria so other things can find it
  Aria::setKeyHandler(&keyHandler);

  // Attach the key handler to a robot now, so that it actually gets
  // some processing time so it can work, this will also make escape
exit
  robot.attachKeyHandler(&keyHandler);

  // modify this next line if you're not using default tcp connection
  tcpConn.setPort();

  // see if we can get to the simulator  (true is success)
  if (tcpConn.openSimple())
  {
    // we could get to the sim, so set the robots device connection to
the sim
    printf("Connecting to simulator through tcp.\n");
    robot.setDeviceConnection(&tcpConn);
      simulator = true;
  }
  else
  {
    // we couldn't get to the sim, so set the port on the serial
    // connection and then set the serial connection as the robots
```

```
    // device

    // modify the next line if you're not using the first serial port
    // to talk to your robot
    serConn.setPort();
    printf(
      "Could not connect to simulator, connecting to robot through
serial.\n");
    robot.setDeviceConnection(&serConn);
      simulator = false;
  }

  // add the sonar to the robot
  robot.addRangeDevice(&sonar);

  // try to connect, if we fail exit
  if (!robot.blockingConnect())
  {
    printf("Could not connect to robot... exiting\n");
    Aria::shutdown();
    return 1;
  }

  // turn on the motors, turn off amigobot sounds
  robot.comInt(ArCommands::ENABLE, 1);
  robot.comInt(ArCommands::SOUNDTOG, 0);

  cout << "Enter Angle: " << endl;
  cin >> angle;

  // the behaviors, the stallRecover behavior uses the defaults
  ArActionStallRecover recover;
  ActionMaintainCompassAngle maintainAngle(angle, simulator, control);

  // add our actions in a good order, the integer here is the priority,
  // with higher priority actions going first
  robot.addAction(&recover, 100);
  robot.addAction(&maintainAngle, 50);

  // run the robot, the true here is to exit if it loses connection
  robot.run(true);

  // now just shutdown and go away
  Aria::shutdown();
  return 0;

}


/*
The definition of ActionMaintainCompassAngle
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "completeVector.h"
```

```
#include "compass.h"

class ActionMaintainCompassAngle : public ArAction
{
public:
  // constructor, sets parameters
  ActionMaintainCompassAngle::ActionMaintainCompassAngle(double angle,
bool simulator, completeVector control);
  // destructor, its just empty, we don't need to do anything
  virtual ~ActionMaintainCompassAngle(void) {myCompass.terminate();};
  // fire, this is what the resolver calls to figure out what this
action wants
  virtual ArActionDesired *fire(ArActionDesired currentDesired);
  // sets the robot pointer, also gets the sonar device
  virtual void setRobot(ArRobot *robot);
protected:
  // this is to hold the sonar device form the robot
  ArRangeDevice *mySonar;
  // what the action wants to do
  ArActionDesired myDesired;
  // used for simulator purposes
  double myAngle;
  // The angle to maintain
  double goalAngle;
  // mySimulator is true if we are using the simulator
  bool mySimulator;
  // The complete vector controls the overall movements of the robot
  completeVector myControl;
  // The compass object
  compass myCompass;
};


/*
ActionMaintainCompassAngle.cpp
Action Maintain Compass is the behavior resposible for checking
the compass data and making sure the robot is facing the proper
direction.  It is not fully implemented into the system due to
i/o difficulties.
*/

#include "Aria.h"
#include <stdio.h>
#include <iostream.h>
#include "ActionMaintainCompassAngle.h"
#include <fstream.h>

const double warningRange = 2.0;
const char BEEP = '\a';
const double weight = 1.0;

/*
  This is the constructor
*/

ActionMaintainCompassAngle::ActionMaintainCompassAngle(double angle,
bool simulator,
```

```
        completeVector control) :
  ArAction("Distance")
{
  myAngle = 0;
  goalAngle = angle;
  myControl = control;
  mySimulator = simulator;

  myCompass.initialize();
}

/*
  Sets the myRobot pointer (all setRobot overloaded functions must do
this),
  finds the sonar device from the robot, and if the sonar isn't there,
  then it deactivates itself.
*/
void ActionMaintainCompassAngle::setRobot(ArRobot *robot)
{
  myRobot = robot;
  mySonar = myRobot->findRangeDevice("sonar");
  if (mySonar == NULL)
    deactivate();
}

/*
  This fire is the whole point of the action.
*/
ArActionDesired *ActionMaintainCompassAngle::fire(ArActionDesired
currentDesired)
{
      double angleError, angle;

    ofstream file;
      file.open("d:\\compassData.txt", ios::app);

      // reset the actionDesired (must be done)
      myDesired.reset();

      angle = myCompass.getAngle(mySimulator, myAngle);
      myAngle = angle;

      angleError = goalAngle - angle;

      // Error checking and logging
      file << "Angle = " << angle << " : Angle Error = " << angleError
<< "\n";
      cout << "Angle = " << angle << " : Angle Error = " << angleError
<< "endl";

      file.close();

      // Call the control (completeVector)
      myControl.addAngle(angleError, weight);

    // now maintain the currentvelocity
```

```
    double velocity = myRobot->getVel();
      myDesired.setVel(velocity);

      // return a pointer to the actionDesired, so resolver knows what
to do
      return &myDesired;
}



/*
Definition for the Compass.cpp function
*/

#include "ComPort.h"
#include "Aria.h"

class compass
{
public:
      // constructor
      compass();
      // deconstructor
      virtual ~compass(void) {};
      // get the angle from the stamp
      double getAngle(bool simulator, double angle);
      // close the port
      void terminate();
      // initialize the port
      bool initialize();
protected:
      // The port object
      ComPort* pComPort;
};


/*
Compass.cpp
Compass contains the functions that actually access the compass.
The comport stuff doesn't really work yet due to i/o irregularities.
*/


#include <stdio.h>
#include <iostream.h>
#include <afxwin.h>         // MFC core and standard components
#include <afxext.h>         // MFC extensions
#include <afxcmn.h>                 // MFC support for Windows Common
Controls
#include "compass.h"

compass::compass()
{
      pComPort = new ComPort();
}

bool compass::initialize()
```

```
{
	if (pComPort->Initialize())
		return true;
	else return false;
}

double compass::getAngle(bool simulator, double myAngle)
{
	if(simulator)
	{
		ArUtil::sleep(1000);

		// get a random number
		double difference = abs(ArMath::random() % 1000);

		// if range is zero, this is the first reading so just
return
		// a random number
		if(myAngle == 0)
			return difference;

		// if the difference is greater than the range, find a
smaller
		// number to use as the difference
		while(difference > myAngle)
			difference = difference - myAngle;

		// output the number, just to see the range we are getting
		cout << "difference:   " << difference << endl;

		return difference;

	} // end simulator portion

	// The "real" method
	else
	{
		char* result = "";
		char myChar = 'a';

		pComPort->Write(&myChar);

		pComPort->Read(result);

		return (double) (long) result;
	}
}

void compass::terminate()
{
	pComPort->Terminate();
}


/*
The definition of the ComPort functions.
*/
```

```
#include <Afx.h>
#include <stdio.h>
#include <iostream.h>

#if
!defined(AFX_COMPORT_H__AD0D66F0_D7CC_11D2_8E68_006008A8250F__INCLUDED_
)
#define AFX_COMPORT_H__AD0D66F0_D7CC_11D2_8E68_006008A8250F__INCLUDED_

#if _MSC_VER >= 1000
#pragma once
#endif // _MSC_VER >= 1000

class ComPort
{
  public:
      ComPort();
      virtual ~ComPort();
      bool Initialize();
      void Read(char* sResult);
      void Terminate();
      void ComWrite(char *write);

  protected:
      HANDLE      hCom;
};

#endif //
!defined(AFX_COMPORT_H__AD0D66F0_D7CC_11D2_8E68_006008A8250F__INCLUDED_
)

/*
ComPort.cpp
ComPort is the function to access data on the serial port.
For some unknown reason, it seems tempermental, and has
some issues. Once this works appropriately, the compass can
be integrated into the rest of the system.
*/

#include "ComPort.h"
#include <windows.h>

ComPort::ComPort()
{} // end constructor CComPort

ComPort::~ComPort()
{} // end destructor CComPort

//
// initialize the com port
//
bool ComPort::Initialize()
{
      // variables used with the com port
      bool     bPortReady;
      CString  sComPort;
```

```
	DCB	dcb;
	COMMTIMEOUTS CommTimeouts;
	bool	bWriteRC;
	bool	bReadRC;
	DWORD	iBytesWritten;
	DWORD	iBytesRead;
	char	sBuffer[128];

	sComPort = "COM1";
	hCom = CreateFile(sComPort,
		GENERIC_READ | GENERIC_WRITE,
		0, // exclusive access
		NULL, // no security, was NULL
		OPEN_EXISTING,
		0, // no overlapped I/O
		NULL); // null template, was NULL


	bPortReady = SetupComm(hCom, 128, 128); // set buffer sizes

	if(bPortReady == false)
		cout << "SetupComm Failed" << endl;

	bPortReady = GetCommState(hCom, &dcb);

	if(bPortReady == false)
		cout << "GetCommState Failed" << endl;

	dcb.BaudRate = 9600;
	dcb.ByteSize = 8;
	dcb.Parity = NOPARITY;
	dcb.StopBits = ONESTOPBIT;
	dcb.fAbortOnError = TRUE;

	bPortReady = SetCommState(hCom, &dcb);

	if(bPortReady == false)
		cout << "SetCommState Failed" << endl;

	bPortReady = GetCommTimeouts (hCom, &CommTimeouts);

	if(bPortReady == false)
		cout << "GetCommTimeouts Failed" << endl;

	CommTimeouts.ReadIntervalTimeout = 50; // was 50
	CommTimeouts.ReadTotalTimeoutConstant = 50; // was 50
	CommTimeouts.ReadTotalTimeoutMultiplier = 10; // was 10
	CommTimeouts.WriteTotalTimeoutConstant = 50; //was 50
	CommTimeouts.WriteTotalTimeoutMultiplier = 10; // was 10

	bPortReady = SetCommTimeouts (hCom, &CommTimeouts);

	if(bPortReady == false)
		cout << "SetCommTimeouts Failed" << endl;

	return bPortReady;
} // end CComPort::Initialize
```

```
// read data from the com port
//
void ComPort::Read(char* sResult)
{
      bool  bWriteRC;
      bool  bReadRC;
      DWORD iBytesWritten;
      DWORD iBytesRead;
      DWORD dwError;
      char  sBuffer[128];
      char  sMsg[512];

      iBytesWritten = 0;
      bWriteRC = WriteFile(hCom, "RE\r", 3, &iBytesWritten, NULL);

      if (!bWriteRC || iBytesWritten == 0)
      {
            dwError = GetLastError();

            printf(sMsg, "Write of length query failed: RC=%d, "
                        "Bytes Written=%d, Error=%d",
                        bWriteRC, iBytesWritten, dwError);
      } // end if

      memset(sBuffer,0,sizeof(sBuffer));
      bReadRC = ReadFile(hCom, &sBuffer, 6, &iBytesRead, NULL);

      if (bReadRC && iBytesRead > 0)
      {
            sResult = sBuffer;
      }
      else
      {
            sResult = "Read Failed";
            dwError = GetLastError();

            printf(sMsg, "Read length failed: RC=%d Bytes read=%d, "
                        "Error=%d ", bReadRC, iBytesRead, dwError);
      } // end if

} // end CComPort::Read

void ComPort::ComWrite(char* mywrite)
{
      DWORD iBytesWritten = 0;
      bool worked, bWriteRC;

      iBytesWritten = 0;

      worked = WriteFile(hCom, mywrite, 1, &iBytesWritten, NULL);

      if(!worked || iBytesWritten < 1)
      {
            cout << "The write did not work!" << endl;
      }
} // end ComPort::Write
```

```
void ComPort::Terminate()
{
      CloseHandle(hCom);
} // end CComPort::Terminate
```

Appendix C - Assignment Algorithm

The problem of getting into formation will utilize the Hungarian assignment algorithm and will move each robot in small increments to avoid collision. The following steps summarize the information given at the aforementioned website (see section 4.6) with adjustments to fit the Formation Robots project.

Given:

1. The distances and angles between all the robots (from the UWB)
2. The distances and angles between the robots of the desired formation

Steps:

1. Select one robot to be the reference robot (0,0)
2. Calculate the center of the robots' current positions
   ((Sum of all x's / number of robots), (Sum of all y's / number of robots))
3. Overlay the center of the current position and the center of the desired formation (see diagram)
4. Create an nxn matrix for n robots
5. Calculate the distance to move each bot to each position – this is the cost function for the assignment algorithm
6. For each row in the matrix, find the smallest element in each row and subtract that amount from every element in the row
7. If there is no marked zero, find a zero and mark it
8. Repeat step seven for each row
9. "Cover" the columns containing a marked zero. If n columns are covered, go to step 13. If not, go to step 10.
10. Find an uncovered zero and prime it. If there are no marked zeroes in this row, go to step 11. Else, cover this row and uncover the column with the marked zero. Repeat until there are no more zeroes. Save the smallest uncovered value and go to step 12.
11. Construct a series of alternating marked and primed zeroes until there is a primed zero without a marked zero in its column. Then unmark each marked zero and mark each primed zero. Uncover and un-prime everything else and return to step 9.
12. Add the value from step 10 to every element of each covered row and subtract it from every element of each uncovered column. Go to step 4.
13. Done – Assignment pairs are indicated by the positions of the starred zeroes.

Output:

1. The robots in the appropriate formation

Appendix D - User Database

D.1 Creating the Necessary Structures

The database was created using MySQL database Server version 4.0.12, additional information can be found at http://www.mysql.com.

The following steps will take you through the process of creating a database and tables which can be accessed via Active Server Pages.

Before a database can be created, it is necessary to go into the DOS window and change your directory to the one containing MySQL. Once there, type in "mysql" to begin using the software and then you can make any changes. The following are commands relating to database construction:

- To create a database: mysql> CREATE DATABASE formationRobots;
- To use the database: mysql> USE formationRobots;
- To create a table: mysql> CREATE TABLE formations (newFlag, numOfRobots, distance1, distanc2, distance3, distance4, angle1, angle2, angle3, angle4);
- To view all existing tables in the database: mysql> SHOW TABLES;
- To view the newly created table: mysql> DESCRIBE formations;

These should be the only commands necessary since information will be added and retrieved from the table via Active Server Pages.

D.2 FormationRobots Tables

There were two tables used in the Graphical User Interface; one to store all information pertaining to the formation and another to contain information on the formation's movement.

The formations table (Table D-1) has a total of 10 possible entries. The first value, newFlag, will be automatically set to '1' so that the formation code knows the table has been updated. The next column displays the number of robots to be in the formation. Currently the user is limited to selecting a formation with two robots since that is how many are supported by UWB for now. The next four columns contain information on the distance to be maintained between robots. The user only has an option to set one distance and that is entered in as 'distance1,' since there is only one measurement needed between the two possible robots. The other three distances are automatically set to NULL. The next four columns contain information for the angle at which each robot needs to be in relation to one another. The angle feature is meant for

future expansion of our design and so is automatically set to NULL.

newFlag	numOfRobots	distance1	distance2	distance3	distance4	angle1	angle2	angle3	angle4
1	2	5	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	1	0	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	10	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1	2	4	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure D-1 Excerpt from Formations Table

The movements table (Table D-2) has a total of five possible entries. The first value, newFlag, will be automatically set to '1' so that the formation code knows the table has been updated. The next column, originalX, is the starting location in distance and should be the same as the originalY from the previous entry. The next column is the originally, and is the starting angle of the formation. The newX will be the distance a user wants the formation to move, and the newY value will be the angle at which the formation will turn. The original values of one line should always be the same as the new values from the previous data row. Currently the values for both originalY and newY will be automatically be set to '0' since this feature has not yet been implemented using angle of arrival.

newFlag	originalX	originalY	newX	newY
1	0	0	6	0
1	5	0	10	0
1	2	0	7	0
1	8	0	4	0

Table D-2 Movement Table

Appendix E - Graphical User Interface Software

E.1 Code for Formation Choice Page

```
<html>
<head>
<title>Select a Formation</title>
<!--This page allows a user to select a formation type and number of
robots that they would like to use-->
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-
1">
</head>
<body bgcolor="#FFFFFF" text="#000000">
<font size="6">Select Number of Vehicles and a Formation </font>

<!--The following is the table containing formation type choices-->
<table width="65%" border="1" height="469">
  <tr>
    <td width="3%" height="20"> </td>
    <td width="25%" height="40">A</td>
    <td width="26%" height="40">B</td>
    <td width="15%" height="40">C</td>
    <td width="15%" height="40">D</td>
    <td width="16%" height="40">
      <p>E</p>
    </td>
  </tr>
  <tr>
    <td width="3%" height="101">2</td>
    <td width="25%" height="101"><a
href="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/B
UTTON%20A-2.htm"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled.jpg" width="173" height="149" border="0"></a></td>
    <td width="26%" height="101"><a
href="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/B
UTTON%20B-2.htm"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled10.jpg" width="173" height="151" border="0"></a></td>
    <td width="15%" height="101"> </td>
    <td width="15%" height="101"> </td>
    <td width="16%" height="101">  </td>
  </tr>
  <tr>
    <td width="3%">3</td>
    <td width="25%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled1.jpg" width="173" height="149"></td>
    <td width="26%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled2.jpg" width="173" height="149"></td>
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled3.jpg" width="173" height="149"></td>
```

```
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled34.jpg" width="173" height="149"></td>
    <td width="16%"> </td>
  </tr>
  <tr>
    <td width="3%">4</td>
    <td width="25%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled5.jpg" width="173" height="149"></td>
    <td width="26%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled6.jpg" width="173" height="155"></td>
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled7.jpg" width="173" height="152"></td>
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled8.jpg" width="173" height="151"></td>
    <td width="16%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled9.jpg" width="173" height="151"></td>
  </tr>
  <tr>
    <td width="3%">5</td>
    <td width="25%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled11.jpg" width="173" height="151"></td>
    <td width="26%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled12.jpg" width="173" height="153"></td>
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled13.jpg" width="173" height="153"></td>
    <td width="15%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled14.jpg" width="173" height="153"></td>
    <td width="16%"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled15.jpg" width="173" height="153"></td>
  </tr>
</table>
<p><font size="4">Click here if done</font><font size="5"> </font>
<object classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="110" height="26" align="top">
    <param name="BASE" value=".">
    <param name=movie
value="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/
button1.swf">
    <param name=quality value=high>
    <param name="BGCOLOR" value="">
    <param name="SCALE" value="noborder">
    <embed
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/bu
tton1.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
```

```
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="110" height="26" bgcolor="" scale="noborder" align="top"
base=".">
    </embed>
  </object>        
         
        <font
size="4">     Click
  Here to Design a New Formation   <object
classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="136" height="30" align="top">
    <param name=movie
value="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/
button3.swf">
    <param name=quality value=high>
    <param name="BGCOLOR" value="">
    <embed
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/bu
tton3.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="136" height="30" bgcolor="" align="top">
    </embed>
  </object></font></p>
<font size="4">  </font>
</body>
</html>
```

E.2 Code for Chosen Formation Page

```
<html>
<head>
<title>BUTTON A-2</title>
<!--this page allows the user to enter in a desired distance to be
maintained between robots-->
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-
1">
</head>

<body bgcolor="#FFFFFF" text="#000000">
<p> </p>
<p><font size="6">You have chosen the following formation</font></p>
<p> </p>
<table width="75%" border="0">
  <tr>
    <td width="50%">
      <div align="center"><img
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/Pi
ctures/untitled.jpg" width="173" height="149"></div>
    </td>
    <td width="50%">
      <p><font size="5">Distance to be maintained between
robots:</font></p>
      <form name="form1" method="post" action="">
```

```
        <input type="text" name="textfield">
      </form>
      <p> </p>
    </td>
  </tr>
</table>
<p> </p>
<table width="75%" border="0" cellpadding="1">
  <tr>
    <td width="48%" height="58"><font size="4"> <font size="5">Click
here to change
      Formation:</font></font></td>
    <td width="52%" height="58"> <object classid="clsid:D27CDB6E-AE6D-
11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="199" height="40">
        <param name=movie
value="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/
button16.swf">
        <param name=quality value=high>
        <param name="BASE" value=".">
        <param name="BGCOLOR" value="">
        <embed
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/bu
tton16.swf" base="."  quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="199" height="40" bgcolor="">
        </embed>
      </object></td>
  </tr>
  <tr>
    <td width="48%" height="48"><font size="5">Click &quot;OK&quot; to
continue:</font></td>
    <td width="52%" height="48"><object classid="clsid:D27CDB6E-AE6D-
11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="199" height="40">
        <param name=movie
value="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/
button17.swf">
        <param name=quality value=high>
        <param name="BASE" value=".">
        <param name="BGCOLOR" value="">
        <embed
src="file:///D|/Documents%20and%20Settings/Administrator/Desktop/gui/bu
tton17.swf" base="."  quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="199" height="40" bgcolor="">
        </embed>
      </object></td>
  </tr>
</table>
<p> </p>
</body>
</html>
```

E.3 Code to Accept User Input

```
<%@ Language=VBScript %>
<!--this code takes input from the user that will be written to the
formationRobots database-->
<html>
<head>
<meta NAME="GENERATOR" Content="Microsoft Visual Studio 6.0">
<title>Add a New Formation</title>
</head>
<body>


<form action="FormationsAddInsert.asp" id="UserEntry" method="post"
name="Form1">

          <td><p> Number of Robots </td>
          <td><p><font color="#000000" face="Arial" size="3"><input
name="numOfRobots" size="3"></font></td>



<table width="75%" border="0">
  <tr>
    <td colspan="4"><font color="#000000"></font></td>
  </tr>
  <tr>
    <td width="33%" height="46"><u><font size="4"
color="#000000">Current Destination</font></u></td>
    <td width="30%" height="46"><u><font size="4"
color="#000000">Desired Destination</font></u></td>
    <td colspan="2" height="46">
      <div align="right"><font color="#000000"><object
classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="176" height="39">
          <param name=movie value="pictures\\button11.swf">
          <param name=quality value=high>
          <param name="BGCOLOR" value="">
          <embed src="pictures\\button11.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="176" height="39" bgcolor="">
          </embed>
        </object></font></div>
    </td>
  </tr>
  <tr>
    <td height="56" width="33%"><font size="4"
color="#000000">Distance: </font>

        <font color="#000000">
        <input type="text" name="textfield" size="10">
        </font>
```

```
    </td>
    <td height="56" width="30%"><font size="4"
color="#000000">Distance: </font>

        <font color="#000000">
        <input name="newX" size="10">
        </font>

    </td>
    <td height="56" width="15%">
          <param name=quality value=high>
          <param name="BGCOLOR" value="">
          <embed src="pictures\\button14.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="100" height="23" bgcolor="">
          </embed>
        </object></font></div>
    </td>
    <td height="56" width="22%">
      <div align="right"><object classid="clsid:D27CDB6E-AE6D-11cf-
96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="100" height="23">
          <param name=movie value="pictures\\button20.swf">
          <param name=quality value=high>
          <param name="BGCOLOR" value="">
          <embed src="pictures\\button20.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="100" height="23" bgcolor="">
          </embed>
        </object></div>
    </td>
  </tr>
  <tr>
    <td width="33%"><font size="4" color="#000000">Angle:  
 </font>

        <font color="#000000">
        <input type="text" name="textfield2" size="10">
        </font>

    </td>
    <td width="30%"><font size="4" color="#000000">Angle:  
 </font>

        <font color="#000000">
        <input name="angle1" size="10">
        </font>

    </td>
    <td width="15%">
      <div align="right"><font color="#000000"><object
classid="clsid:D27CDB6E-AE6D-11cf-96B8-444553540000"
```

```
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="100" height="23">
          <param name=movie value="pictures\\button15.swf">
          <param name=quality value=high>
          <param name="BGCOLOR" value="">
          <embed src="button15.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="100" height="23" bgcolor="">
          </embed>
        </object></font></div>
    </td>
    <td width="22%">
      <div align="right"><object classid="clsid:D27CDB6E-AE6D-11cf-
96B8-444553540000"
codebase="http://download.macromedia.com/pub/shockwave/cabs/flash/swfla
sh.cab#version=4,0,2,0" width="100" height="23">
          <param name=movie value="pictures\\button21.swf">
          <param name=quality value=high>
          <param name="BGCOLOR" value="">
          <embed src="button21.swf" quality=high
pluginspage="http://www.macromedia.com/shockwave/download/index.cgi?P1_
Prod_Version=ShockwaveFlash" type="application/x-shockwave-flash"
width="100" height="23" bgcolor="">
          </embed>
        </object></div>
\tab
    </td>
\tab
\tab
</table>
<table>
\tab\tab <tr>
\tab
          <td width="22%"><div align="center"><center><p><input
id="reset1" name="reset1" type="reset" value="Reset"></td>
          <td width="22%"><div align="center"><center><p><input
id="submit1" name="submit1" type="submit" value="Submit"></td>
        </tr>
 </table>
</body>
</html>
```

E.4 Code to write to Database

```
<%@ Language=VBScript %>

<!--Currently tthe distance between robots value is always being set to
7, this is because this page does not have
a field for the user to enter the desired distance, and the desired
distance information has not been entered
yet.  The first set of update values is for the formations table, the
second update is for the movement update.
The reason for this is that the code is still in testing stages. The
informatoin will be written as a row into
the appropriate tables in the formationRobots database-->
```

```
<html>
<head>
<meta NAME="GENERATOR" Content="Microsoft Visual Studio 6.0">

<body>
<%
Session.timeout = 5
    Set DB = Server.CreateObject("ADODB.connection")
\tab DB.Open "FormationRobots"

' get data from interactive page form
    'set newFlag1 = 1;
    set numRobots = Request.Form("numOfRobots")
    set dist1 = Request.Form("newX")
    set ang1 = 0;

' update values in database
    InsertString = "INSERT INTO Formations (newFlag, numOfRobots,
distance1, angle1)"
    InsertString = InsertString & " VALUES ('" & 1 & "', "
    InsertString = InsertString & "'" & numRobots & "', "
    InsertString = InsertString & "'" & 7 & "',"
    'InsertString = InsertString & "'" & NULL & "', "
    'InsertString = InsertString & "'" & NULL & "', "
    'InsertString = InsertString & "'" & NULL & "', "
    InsertString = InsertString & "'" & 0 & "') "
    'InsertString = InsertString & "'" & NULL & "', "
    'InsertString = InsertString & "'" & NULL & "', "
    'InsertString = InsertString & "'" & NULL & "') "
    response.write InsertString  & "<BR>"
    DB.Execute(InsertString)

'update values in database
\tab InsertString = "INSERT INTO Movement (newFlag, originalX,
originalY, newX, newY)"
\tab InsertString = InsertString & " VALUES ('" & 1 & "', "
\tab InsertString = InsertString & "'" & 0 & "', "
\tab InsertString = InsertString & "'" & 0 & "',"
\tab InsertString = InsertString & "'" & dist1 & "',"
\tab InsertString = InsertString & "'" & 0 & "') "
\tab response.write InsertString  & "<BR>"
    DB.Execute(InsertString)


%>

</body>
</html>
```

Appendix F - Project Budget

Appendix

Project Budget

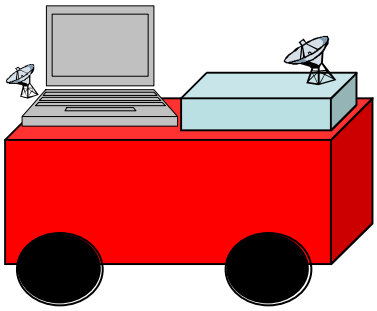
Supplied By SCU Robotics Department

- ActivMedia Pioneer 2 AT Robot		3 x $6000
- IBM ThinkPAD laptop		4 x $600
- TimeDomain Ultra Wideband Device		2 x $20,000
	Total:	~ $60,400

Supplies by SCU $1000 Grant

- 128MB RAM for laptop		4 x $50
- Netgear 4-port Dual Speed Hub		$50
- Radio Shack RC Car Battery		3 x $30
- USB to Serial Cable		2 x $40
- Parts for UWB power pack		2 x $10
- Parts for HUB power pack		$15
- Mounting & brackets for Robot		3 x $15
	Total:	~ $500

User Manual



1. Setup

Using Serial cord, connect the laptop with the Pioneer robot. The Pioneer serial port is located on the back by the battery bay. Next connect the Ultra Wide Band unit to the laptop using the Ethernet LAN cord. Last of all, insert Wireless Network card into the PCI slot. View diagram below for help (Figure G-1).

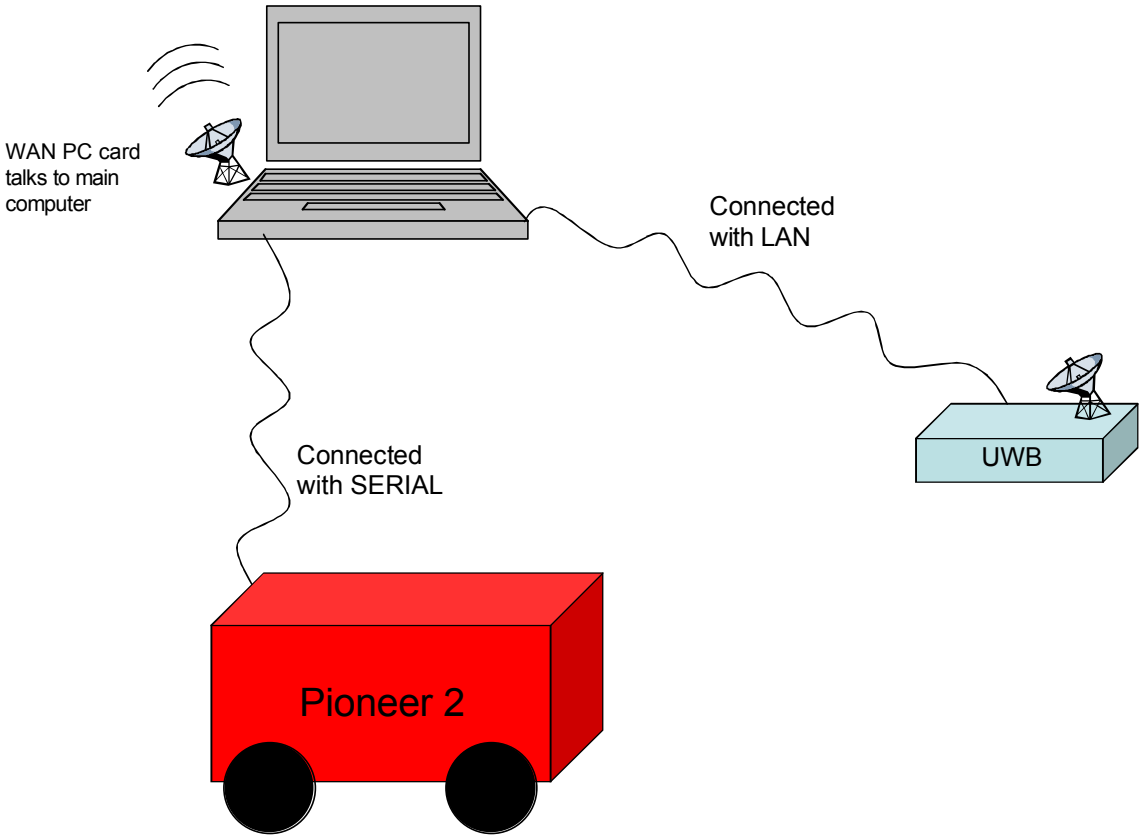


Figure G-1 System Setup

2. Before Operation

Before you can begin giving commands to your robots via a GUI program on your main CPU a few functionality checks should be made. Check to see that all battery packs mounted on the robots are fully charged and that the robots are turned on. Also, make sure the laptop mounted on each robot is turned on with a fully charged battery. The laptops will function as communicators between the GUI run on the main CPU and the robots. Once this is done switch on your main CPU and begin the program. You are now ready to begin directing your Pioneer robot formation!

3. Defining a Robot Formation

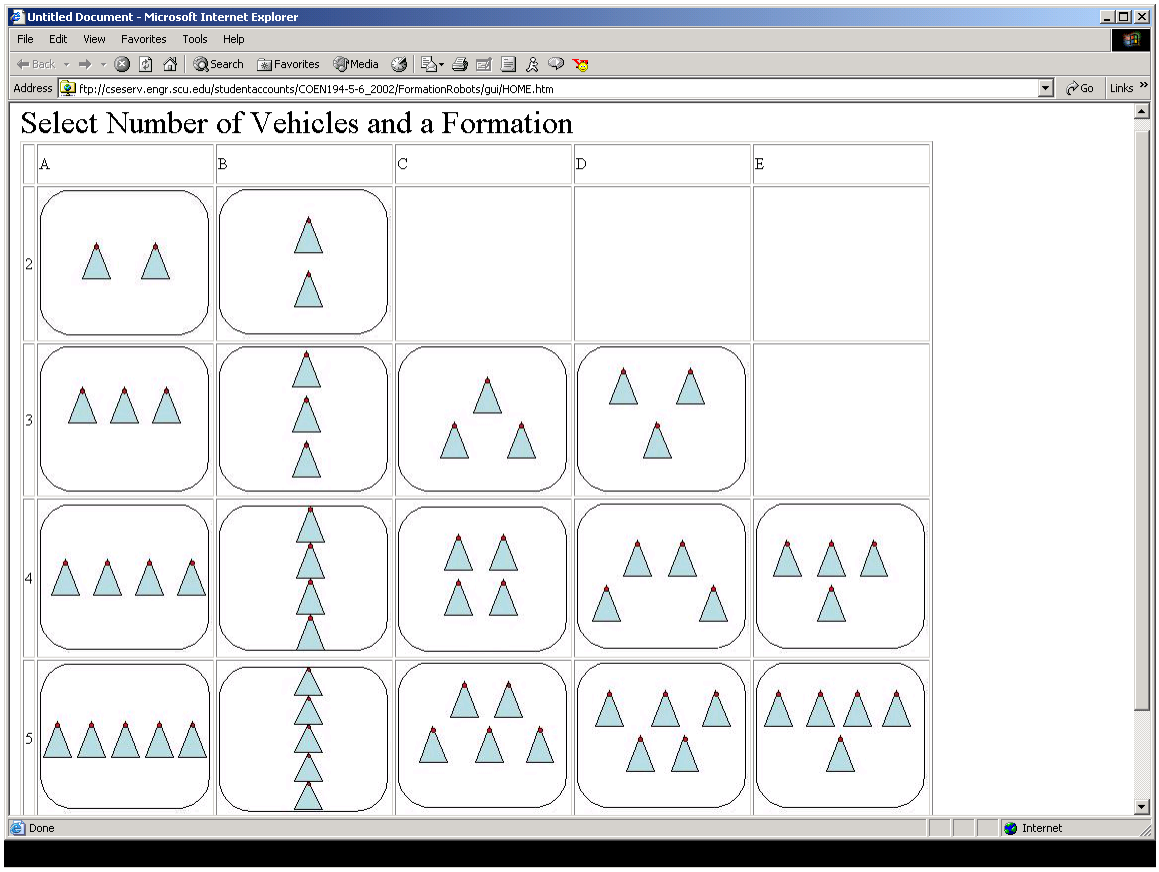


Figure G-2 Formation Choices

Once you have opened your Robot Formation program, you will be brought to a page looking similar to the screen shot above. Click on the formation you wish to choose, and then click **OK**. Please note that the **OK** button and the **DESIGN FORMATOIN** buttons are not visible in the shot above, but are situated below the last row of formation options. By selecting one of the predetermined formations, you are choosing the number of robots and formation type portrayed in the picture. If you wish to design your own robot formation, click on **DESIGN** and you can create your own formation. This will be explained later in the section.

3.1 Choosing a Predetermined Formation

Once you have selected your formation choice, you will be taken to a screen which looks similar to the screen shot below (Figure G-3). You will be asked to define a **DISTANCE TO BE MAINTAINED BETWEEN ROBOTS**. This distance will be the distance kept between any two robots. It is recommended to keep a minimum distance of one and a half times the robots' length between your robots.

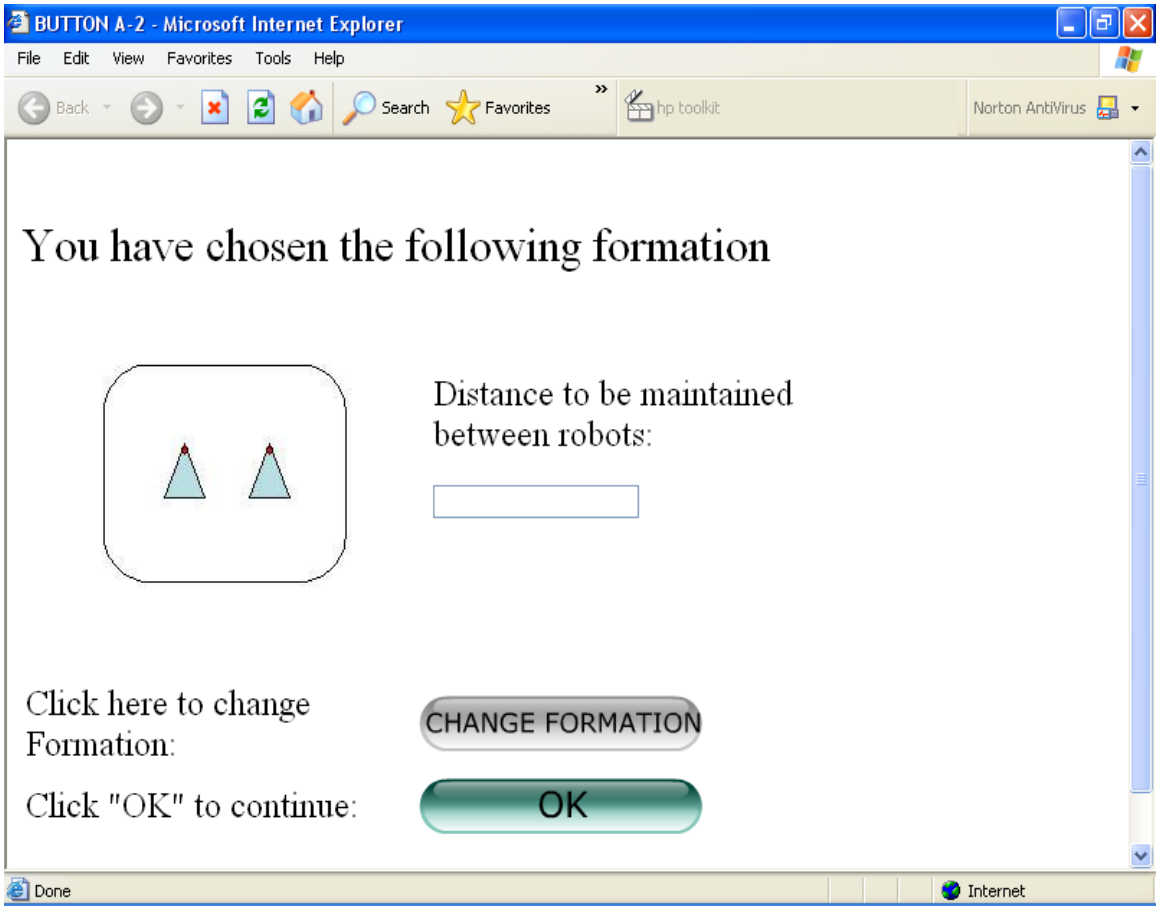


Figure G-3

Once you have made your selections, click the **OK** button at the bottom of the window. This will close the window so that only the main screen with the grid and main user options will be viewable. As soon as you have clicked on **OK**, the robots will get into the formation you have just designated. At any time if you are unhappy with your decisions and wish to reselect the number of robots, distance between them, or formation type, you may click the **CHANGE FORMATION** button located on the bottom of the page.

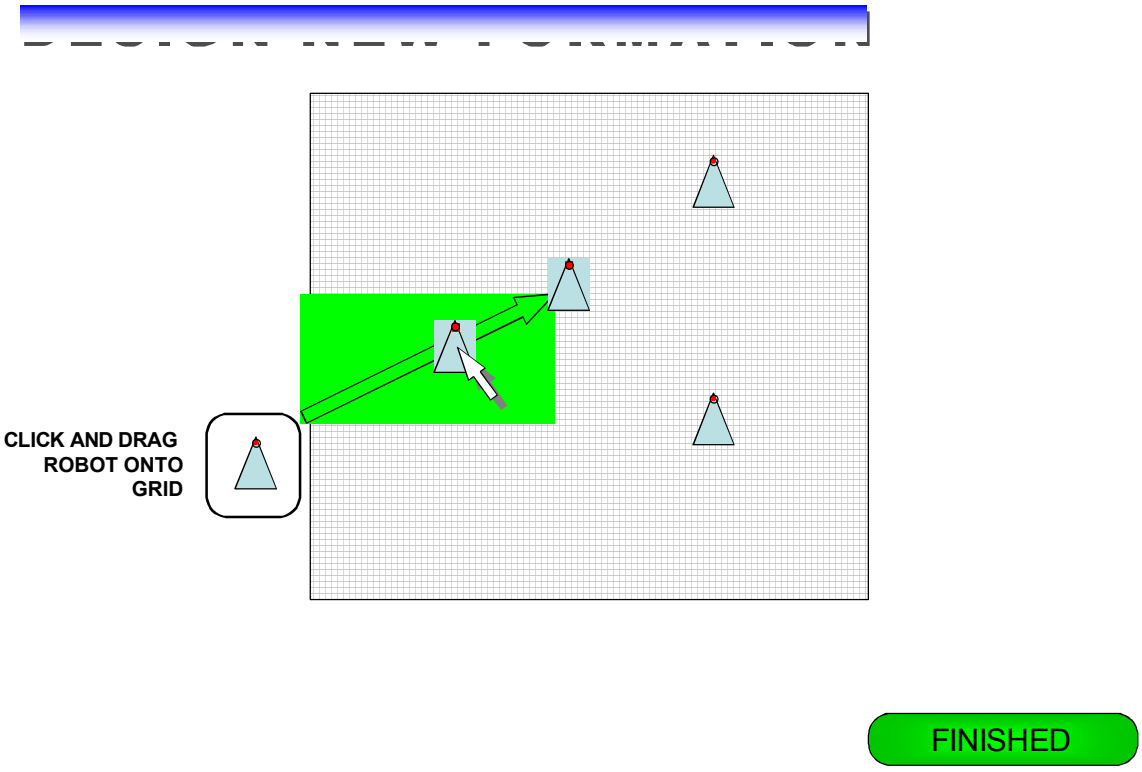


Figure G-4

3.2 Designing your Own Formation

This section is yet to be implemented, but in the future a new formation can be created by user in the following manner. If you do not want to select one of the predetermined formations, click on the **DESIGN** button which is at the bottom of screen shot located at the beginning of section 3 (Figure G-2, actual design button not pictured). Now, you will be taken to a new screen looking similar to the one above (Figure G-4). To the left of the grid is a button with a picture of a robot on it. To add a new robot to your formation simply click the button, and while still holding down on the mouse, drag the robot to the place on the grid where you wish to place it. Once you have put the robot in the proper location, release the mouse button. Continue this step until you have the number of robots you want, and in their proper positions on the screen. If you wish to relocate a robot, once again click on it and drag it to its new location. To remove a robot, click on it once and then hit the delete button. When you have finished designing your formation, click on **FINISHED.** You will be taken to the "Your Formation Choice Page." If you have any questions on this part, refer to Section 3.1.

4. Moving your Formation

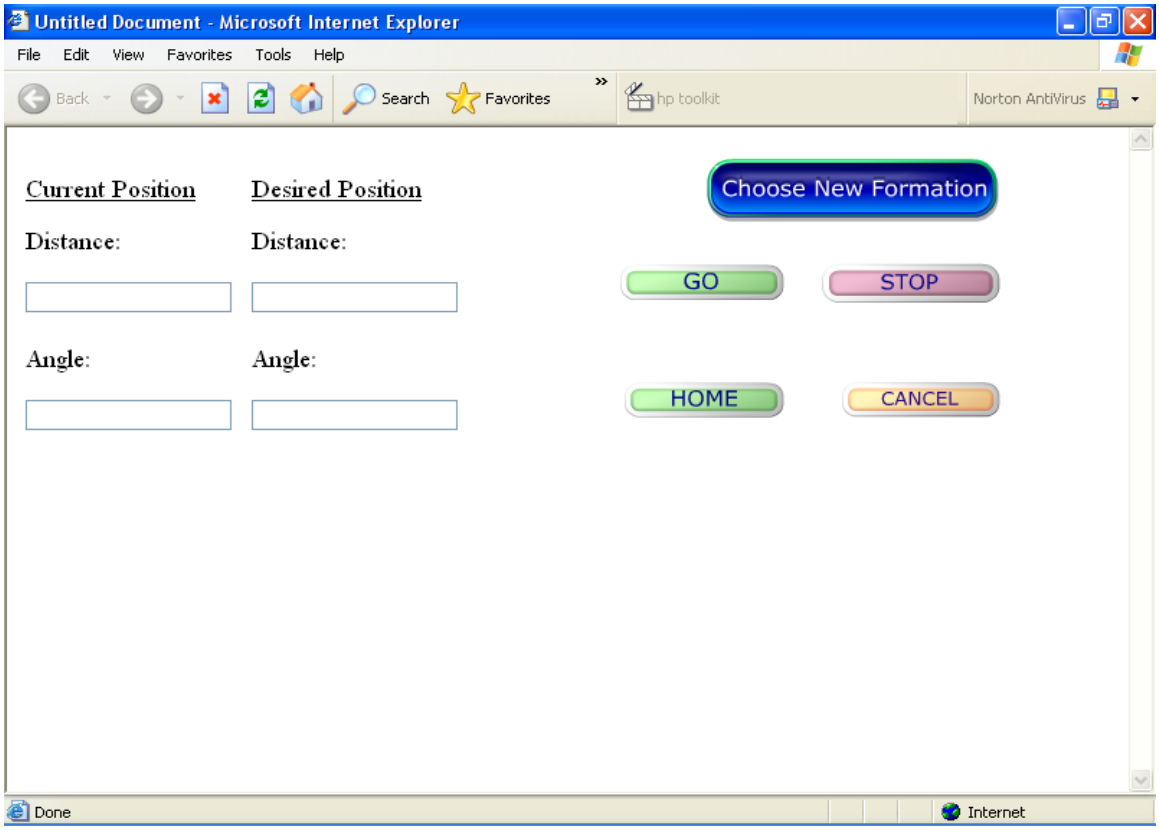


Figure G-5

4.1 Formation Movement

Advanced instructions may be given to the robot formation if the desired distance and angle of rotation are known. There are fields displaying current position and desired position information for the formation, these fields are labeled **Distance** and **Angle**. In the **Distance** field you can enter in the distance in which you want the formation to travel. The **Angle** field will take whole numbers ranging from 0 to 360. Whichever direction your robots are facing will be considered to be the (0,0) coordinate, so give your angle of desired rotation accordingly. Once you have filled in these two fields, click the **GO** button, which is to the right of the **Distance** and **Angle** fields.

To move the formation again, reenter the desired distance and angle to be turned before hitting **GO.** If at any time you wish to return to your original starting point hit **Home**, which is located on the right of your screen. If it is not possible to get all robots to the new location, you will receive a warning message. Also, don't worry if your formation does not get to the new location immediately. It may take a while for a clear path to be

found, and the time out mechanism will not come into effect until either all options have been exhausted, or the time allotted for the movement has expired.

5. Trouble Shooting

Various problems may occur during operation of your robot formation. Some common problems and their quick fixes are listed below.

- **One of the robots experienced power failure.** In this case you have two options. Depending on where the robots are being used, it may be possible to go over to the robot and check the battery pack. If you can switch the battery or in any way power up the robot again, the formation can continue as it had before the power failure. If this does not work, your screen will ask you what you wish to do. You may simply tell the formation to continue on with n-1 robots in the same formation, or you can request a new formation. If after a certain amount of time you do not give the robots a command, a default time out will occur and the robot formation will continue on in the same formation with n-1 robots.

- **The robot formation doesn't seem to be receiving my commands.** In this case there may be a problem with the network cards used by the laptops mounted on the robots. Check to see that all the cards are installed and functioning correctly.

- **The robots are not reaching the specified location no matter how many attempts are made.** It is possible that the desired location is not reachable. In this case, choose another destination for the robots to relocate to, or try choosing a different robot formation. By doing so, the new formation may be able to maneuver around the obstacle that was unavoidable with the previous formation.

- **After I have chosen the number of robots, I cannot find the desired formation.** It is possible that the formation you are searching for is not predefined for the number of robots you have chosen. You can either choose the number of robots that go with your desired formation or attempt to define your own formation.

References

[1] Pioneer 2 Operations Manual, ActivMedia Robtics, 2001 (http: //robots.activmedia.com)

[2] http://www.robot-electronics.co.uk/htm/cmpsdoc.shtml

[3] http://www.robot-electronics.co.uk/htm/cmps2bs2.shtml

[4] Mysql++ A C++ API for Mysql, ver 1.7.9 by Kevin Atkinson and Sinisa Milivojevic, access it online at: http://www.mysql.com/documentation/mysql++/index.html

[5] http://campus.murraystate.edu/academic/faculty/bob.pilgrim/445/algorithms_7.html

[6] Aria Reference Manual, 1.1.5, Generated by Doxygen 1.2.10, 2002, ActivMedia Robotics

[7] MySQL Reference Manual for version 4.0.12